NASA Technical Memorandum 4273

Cryogenic Wind Tunnels

A Comprehensive, Annotated Bibliography

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Contents

Current Cryogenic Wind Tunnels

Organization	Tunnel	Test Gas	Test Section Size (h,w,l), m	Speed or Mach Range	Stagnation Pressure, bar	Stagnation Temperature	Running Time
RAE-Bedford	closed circuit, centrifugal fan	nitrogen	0.3 x 0.3 x 1.5	up to 25 m/s	atmospheric	90 K - ambient	typically 1 hour
University of Southampton	closed circuit, fan	nitrogen	0.11 x 0.11 x 0.25 (regular) 0.14 x 0.11 x 0.41 (MSBS)	14 - 72 m/s	atmospheric	79 - 380 K	typically 1 hour
ETW GmbH	PETW closed circuit, fan	nitrogen	0.23 x 0.27 x 0.78	0.35 - 1.0 continuous 1.2, 1.35 fixed nozzles	1.25 - 4.5	90 - 313 K	typically 1 hour
ONERA - CERT	T2 closed circuit, induction	nitrogen rich air	0.37 x 0.39 x 1.32 solid adaptive walls	0.3 - 1.0	1.6 - 5.0	95 K- ambient	up to 100 sec+
DLR - Köln	KKK closed circuit, fan	nitrogen	2.4 x 2.4 x 5.4	up to 0.38	up to 1.12	100 - 300 K	up to several hours
DLR - Göttingen	Ludwieg tube	nitrogen	0.40 x 0.35 x 2.0	0.25 - 1.0	up to 10	120 K - ambient	about 1 sec
NAL (Japan)	closed circuit, fan	nitrogen	0.1 x 0.1 x 0.3	up to 1.02	up to 2	90 K - ambient	more than 2 hours
University of Tsukuba	closed circuit, fan	nitrogen	0.1 x 0.1 x 0.3	up to 30 m/s	up to 2	100 K - ambient	up to 2 hours
University of Tsukuba	closed circuit, fan	nitrogen	0.5 x 0.5 x 1.2	7 - 65 m/s	1.22 - 8.10	112 K - ambient	30 min. at max. R
NDA (Japan)	closed circuit, centrifugal fan	nitrogen	0.30 x 0.06 x 0.72	up to 0.83	up to 1.77	108 K - ambient	up to 100 min.
University of Illinois	closed circuit, fan	nitrogen	1.22 x 0.60 x 1.0	0 - 8 m/s	atmospheric	80 - 300 K	several minutes
NASA Langley	0.3-m TCT closed circuit, fan	nitrogen	0.33 x 0.33 x 1.42 solid adaptive walls	0.05 - 1.0+	1.1 - 6.2	78 - 340 K	up to several hours
NASA Langley	U.S. NTF closed circuit, fan	nitrogen	2.5 x 2.5 x 7.62 slotted	0.2 - 1.20	1.0 - 8.9	78 - 340 K	up to several hours
TsAGI (U.S.S.R.)	T-04 closed circuit, induction	nitrogen rich air	0.2 x 0.2 x 0.74 perforated	0.1 - 1.15	1 - 6.5	100 - 300 K	1.5 hours
ITAM (U.S.S.R.)	MT-324 closed circuit, fan	nitrogen	0.2 x 0.2 x 0.8	up to 0.2	atmospheric	80 - 300 K	several hours
PMI-K (U.S.S.R.)	closed circuit, fan	mixtures of gases	0.22 circular open jet	0.5 - 10 m/s	1 - 10	130 - 300 K	?
CARDC (China)	closed circuit, fan	nitrogen	0.1 x 0.1	up to 0.4	atmospheric (?)	79 - 320 K	?

RK Nov 6 1990

INTRODUCTION

The purpose of this bibliography is to provide a reference list of documents that would be useful to anyone interested in building or using a cryogenic wind tunnel. For this bibliography, we define a cryogenic wind tunnel as one that can operate with stagnation temperatures below -150 °F. A table of all cryogenic wind tunnels known to the authors is given on the previous page.

This bibliography contains 638 citations. It updates and supersedes previous NASA bibliographies on cryogenic wind tunnels. This updated version includes 171 additional citations. The arrangement is chronological by date of publication in the case of reports, and by presentation in the case of papers. Included in this bibliography are some publications of historical interest which relate to key events in the evolution of cryogenic wind tunnels. Thus, this bibliography also serves as a history of the development of cryogenic wind tunnels. Compilations of papers presented at meetings, conferences, symposiums, and so forth, are placed under the dates of publication.

We have changed the numbers assigned to the citations from those used in the previous bibliographies. We did this so that we could remove some outdated citations and add some recently discovered older works in their proper chronological order.

We have attempted to include all of the relevant literature. However, we have not included some papers because of insufficient information on where and when they were published.

We have included in an appendix several books, papers, and bibliographies that, although not dealing directly with cryogenic wind tunnels, are useful sources of information.

We included author, sources, and subject indices to increase the usefulness of this compilation.

Often, we used abstracts from the NASA announcement bulletins *Scientific and Technical Aerospace Reports (STAR)* and *International Aerospace Abstracts (IAA).* In other cases, we have used abstracts written by the authors. We modified and shortened some abstracts, using only parts pertinent to the subject of the bibliography. The information included about the authors was correct at the time the papers were written. It may not have remained the same. We have noted those items which appear in several forms. We include accession numbers, report numbers, and other identifying information in the citations to ease the filling of requests for specific items. Most of the citations in this bibliography may be obtained by requesting from a NASA library. When requesting material, it is best to include the complete identifying information.

Publications relevant to cryogenic wind tunnels are announced as they become available in a newsletter devoted to cryogenic tunnels, *CRYO Newsletter*. If you want to receive copies of *CRYO Newsletter*, send your name and address to

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Ordering information for the various types of materials is listed on the following page.

ORDERING INFORMATION

Ordering sources for the different types of materials are given below:

Accession Number	Type of Material	Source
A??-????? Example: A88-12345	AIAA papers and worldwide literature from conferences and periodicals available from AIAA.	American Institute of Aeronautics and Astronautics Technical Information Service 555 West 57th Street, 12th Floor New York, NY 10019
N??-????? Example: N77-12345	Report literature having no distribution limitations.	National Technical Information Service (NTIS) 5285 Port Royal Road Springfield, VA 22161 USA
X??-????? Example: X66-12345	Report literature with distribution limitation of some type.	NASA Scientific and Technical Information Facility (STIF) P. O. Box 8757 B.W.I. Airport, MD 21240 USA
AD-?????? ATI-?????? Example: AD-A162351	Report literature which has been declassified	Defense Technical Information Center Defense Logistics Agency Cameron Station Alexandria, VA 22314 USA
N-?????	Pre-1962 reports and papers.	NASA libraries
Example: TL123 C66	Books	Libraries

Please note that a "#" after an acquisition number (for example A66-12345#) indicates that the document is also available in microfiche form.

BIBLIOGRAPHY

1. *Margoulis, W.: Nouvelle Methode d'essai de Modeles en Souffleries Aerodynamiques. **(A New Method of Testing Models in Wind Tunnels.)** Competes Rendus Acad. Sci., vol. 171, 1920, pp. 997-999, Seance du 22 November 1920.

This is a short version (abstract), in French, of NACA TN-52. M. L. Lecornu presented this paper for W. Margoulis.

*NACA, Paris Office, France

2. *Margoulis, W.: **A New Method of Testing Models in Wind Tunnels.** NACA TN-52, August 1921, 20 pp.

This paper discusses the use of gases other than air and the use of nonambient temperatures and pressures as ways of increasing test Reynolds number and reducing capital cost and drive-power requirements for low-speed wind tunnels. This paper examines in detail the use of carbonic acid gas (CO_2).

*NACA, Paris Office, France

3. *Smelt, R.: **Power Economy in High-Speed Wind Tunnels by Choice of Working Fluid and Temperature.** British R.A.E. Rep. no. Aero 2081, August 1945.

NASA Langley Technical Library Number 5341
236

The power required to operate a high-speed wind tunnel at fixed Mach number, Reynolds number, and pressure can be greatly reduced if, instead of air at normal temperatures, other fluids or low temperatures are used. If operation at normal temperatures is desired, best power economy is obtained by using certain fluorine compounds of high molecular weight. The value of γ for all these substances is low–about 1.15, compared with 1.4 for air. No substance is known which will permit substantial power reduction at normal temperature with $\gamma=1.4$. If $\gamma=1.4$ is essential–nothing definite can be said on this point–then power economy is best achieved by refrigeration. This is permissible down to a definite limiting temperature. For air, the limit is 126 °R and the power there is only 7 percent of that at normal temperature. Use of nitrogen permits an operating temperature of 108 °R, and the power required is 3.8 percent of that for air at normal temperatures.

*Royal Aircraft Establishment, Bedford, Beds MK41 6AE, England

4. Pankhurst, R. C.; and Holder, D. W.: **Power Economy by Reduction of Stagnation Temperature.** Wind Tunnel Technique, Sir Isaac Pitman and Sons, Ltd., London, 1952, pp. 45-47.

NASA Langley Technical Library Number TL567.W5P3

The advantages with respect to power economy of a reduction in stagnation temperature are noted. "Since refrigeration does not involve an increase in the stresses in the model nor a departure from the conditions of dynamic similarity, it might appear to be a promising method of power economy. The practical difficulties involved would be considerable."

5. *Fowler, H. S.; and *Rush, C. K.: **Centrifugal Compressors–A Brief History and a Description of Some Current Research.** Quarterly Bulletin of the Division of Mechanical Engineering, National Research Council of Canada, October - December 1962, pp. 35-54. Also, Canadian Aeronautics and Space Journal, January 1964, pp. 7-12.

N63-13998

A brief account of the historical development of the centrifugal compressor shows a continued improvement until a peak was reached about 1955. After some years of neglect, interest is now reawakening in this field. Following a very short review of some aspects of compressor theory, two novel experimental approaches to the study of flow and efficiency in the compressor are described. The test rigs being used in these studies in the Mechanical Engineering Division of NRC are illustrated. One of these rigs, the heat exchanger of which is cooled with liquid nitrogen, is of special interest.

*National Research Council of Canada, Montreal Rd., Ottawa, Ont K1A 0R6, Canada

6. *Rush, C. K.: **A Low Temperature Centrifugal Compressor Test Rig** (Mechanical Engineering Report). National Research Council of Canada Rep. MD-48; NRC-7776, November 1963, 57 pp., 9 refs.

N64-25199

An examination of the requirements for dynamic similarity in centrifugal compressors demonstrates the possible advantages of using air at temperatures down to 100 K. A test rig capable of operating at low temperatures is described. Test results for inlet conditions, ranging from room temperature to 125 K, are presented. The predicted advantages of operating at low temperature are confirmed. However, the desired result that the performance should be identical at four different conditions of dynamic similarity was not achieved although the differences are relatively small. Further examination of the results suggests that the differences are due to changes in geometry with changes in the test rig internal pressure.

*National Research Council of Canada, Montreal Rd., Ottawa, Ont K1A 0R6, Canada

7. *Goodyer, M. J.; and **Kilgore, R. A.: **The High Reynolds Number Cryogenic Wind Tunnel.** AIAA paper 72-995, 7th Aerodynamic Testing Conference, Palo Alto, Calif., September 13-15, 1972. Also, AIAA Journal, vol. 11, no. 5, May 1973, pp. 613-619, 9 refs.

AIAA Paper 72-995 A72-41581#

Theoretical considerations indicate that cooling the wind-tunnel test gas to cryogenic temperatures will provide a large increase in test Reynolds number with no increase in dynamic pressure while reducing the tunnel drive-power requirements. We have made studies to determine the expected variations of Reynolds number and other parameters over wide ranges of Mach number, pressure, and temperature with due regard to avoiding liquefaction and adverse real-gas effects. We have developed practical operational procedures in a low-speed prototype cryogenic wind tunnel. Aerodynamic experiments in the tunnel have demonstrated the theoretically predicted variations in Reynolds number and drive power. Force and moment measurements on a wing model mounted on a water-jacketed strain-gage sting balance have demonstrated the feasibility of operation of such balances in a cryogenic environment.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

8. *Lin, S.-C.: **An Experimental Study of Gasdynamical Turbulence.** California Univ., San Diego, Ph.D. Thesis, 1972, 230 pp. (Available Univ. Microfilms, Order no. 72-24634).

N73-19280

A nearly homogenous grid turbulence field with large-amplitude temperature fluctuations is studied experimentally. To generate a nearly homogenous flow field with large temperature fluctuations in the laboratory, a 21- by 21-Foot variable density, subsonic wind tunnel capable of generating Reynolds number per inch up to 3.5×10^4 when operated at ambient temperatures and up to 3.0×10^5 when operated at 100 K, by the direct injection of liquid nitrogen, has been designed and developed. The details of the design and a discussion of the tunnel performance are given. Operation of the tunnel has been postponed.

*University of California, 10995 Le Conte Avenue, Los Angeles, CA 90024 U.S.A.

9. *Jacobsen, R. T.; *Stewart, R. B.; *McCarty, R. D.; and *Hanley, H. J. M.: **Thermophysical Properties of Nitrogen from the Fusion Line to 3500 R (1944 K) for Pressures to 150,000 psia (10342 × 10^5 N/m^2).** National Bureau of Standards, NBS TN-648, December 1973, 162 pp., 36 refs. (Available from U.S. Government Printing Office, Washington, DC 20402, Catalog #C13.46:648.)

N74-17637#

Tables of thermophysical properties of nitrogen are presented for temperatures from the fusion line to 3500 R for pressures to 3000 psia and from the fusion line to 1500 R for pressures above 3000 psia to 150,000 psia. The tables include values of entropy, enthalpy, internal energy, density, specific volume, velocity of sound, specific heats (C_v and C_p), thermal conductivity, viscosity, thermal diffusivity, Prandtl number, and the dielectric constant for selected isobars. Additional tables are included for values of $(\partial P/\partial V)_T$, $(\partial P/\partial T)_\rho$, $V(\partial H/\partial V)_\rho$, $(\partial P/\partial U)_v$, $V(\partial P/\partial V)_T$, and $(\partial V/\partial T)_\rho$, which have special utility in heat-transfer calculations. Tables of selected isobars for the liquid and vapor phases and for the saturated vapor and saturated liquid are included. An equation of state is presented for liquid and gaseous nitrogen for the temperature and pressure ranges of these tables. A vapor-pressure equation, a melting-curve equation, and an equation to represent the ideal-gas-heat capacity of nitrogen are also given. The equation of state is estimated to be accurate to within 0.5 percent in the liquid region, to within 0.1 percent for supercritical isotherms up to 15,000 psia, and to within 0.3 percent from 15,000 to 150,000 psia. The vapor-pressure equation is accurate to within ±0.01 K between the triple point and the critical point.

*National Bureau of Standards, Boulder Laboratories, Boulder, CO 80302 U.S.A.
Contract NASA-MSC-T-1813A

10. *Kilgore, R. A.; *Adcock, J. B.; and *Ray, E. J.: **Flight Simulation Characteristics of the Langley High Reynolds Number Cryogenic Transonic Tunnel.** 12th Aerospace Sciences Meeting, Washington, DC, January 30 - February 1, 1974, 9 pp., 3 refs.

AIAA Paper 74-80 A74-20761#

This paper describes the characteristics of the NASA Langley 34-cm (13.5-in.) pilot cryogenic transonic pressure tunnel. It also gives the results of initial tunnel operation. Tests of a two-dimensional airfoil at a Mach number of 0.85 show identical pressure distributions for a chord Reynolds number of 8.6 million obtained first at a stagnation pressure of 4.91 atm at a stagnation temperature of +120 °F and then at a stagnation pressure of 1.19 atm at a stagnation temperature of -250 °F.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

11. *Kilgore, R. A.: **The Cryogenic Wind Tunnel for High Reynolds Number Testing.** Southampton Univ., England Ph.D. Thesis, February 1974. NASA TM X-70207, 230 pp., 30 refs.

N74-27722#

Experiments at the NASA Langley Research Center in a cryogenic low-speed continuous-flow tunnel and in a cryogenic transonic continuous-flow pressure tunnel have demonstrated the predicted changes in Reynolds number, drive power, and fan speed with temperature while operating with nitrogen as the test gas. The experiments have also demonstrated that it is easy to cool to cryogenic temperatures by spraying liquid nitrogen directly into the tunnel circuit. We can control tunnel temperature to very close limits. Most types of wind tunnels could operate with an advantage at cryogenic temperatures. The continuous-flow, fan-driven tunnel is particularly well suited to take full advantage of operating at these temperatures. A continuous-flow, fan-driven cryogenic tunnel to satisfy current requirements for test Reynolds number can be built and operated using existing techniques. Both capital and operating costs appear acceptable.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

12. *Adcock, J. B.: **The Cryogenic Wind Tunnel Concept.** (Presented during the House Authorization Subcommittee Hearings on the OAST FY '75 Budget.) NASA TM-80504, March 1974, 13 pp. (NASA only).

X80-70012#

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

13. *Wilson, J. F.; *Ware, G. D.; and *Ramsey, J. W., Jr.: **Pilot Cryo Tunnel: Attachments, Seals, and Insulation.** Presented at the ASCE National Structural Meeting, Cincinnati, Ohio, April 22-26, 1974. NASA TM-80509, 1974, 30 pp., 1 ref.

N79-30244#

This paper describes tests made in evaluation of flange attachment seals and the structural support insulation for a pilot cryogenic wind tunnel. The overall dimensions of the pilot tunnel are 9.9-m long, 3.7-m high, and 1.2-m maximum diameter, with a 0.34-m octagonal test section and a 12:1 contraction ratio. The fan-driven, closed-circuit tunnel at the NASA Langley Research Center was designed for operation at cryogenic nitrogen temperature; it required knowledge of material behavior and performance in addition to that available from the literature. The design conditions for the tunnel are pressures up to 5 atm (507 kPa) and temperatures from 78 K (-320 °F) to 322 K (+120 °F). The cold temperature, together with the high pressure, required tests and studies in the following areas: compatible bolting, adequate sealing, and effective thermal insulating materials.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

14. *Zapata, R. N.; *Humphris, R. R.; and *Henderson, K. C.: **Experimental Feasibility Study of the Application of Magnetic Suspension Techniques to Large-Scale Aerodynamic Test Facilities.** AIAA 8th Aerodynamic Testing Conference, Md., July 8-10, 1974, 11 pp., 9 refs.

AIAA Paper 74-615 N80-11102# A74-35383#

Note: This was also published as NASA CR-146761, 1975, 10 pp.

Based on the premises that magnetic suspension techniques can play a useful role in large-scale aerodynamic testing and superconductor technology offers the only practical hope for building large-scale magnetic suspensions, an all-superconductor, three-component magnetic suspension and balance facility was built as a prototype and was tested successfully. Quantitative extrapolations of design and performance characteristics of this prototype system to large systems compatible with existing and planned high-Reynolds-number tunnels were made. They show this experimental technique should be particularly attractive when used with large cryogenic wind tunnels.

Note: Similar information is contained in AGARD-CP-174 (N76-25213#) and in NASA CR-2565 (N75-28025).

*University of Virginia, Charlottesville, VA 22904 U.S.A.
NASA Grants NGR-47-005-029; NGR-47-005-110; NGR-47-005-112; and NSG-1010.

15. *Ray, E. J.; *Kilgore, R. A.; *Adcock, J. B.; and *Davenport, E. E.: **Test Results From the Langley High Reynolds Number Cryogenic Transonic Tunnel.** 8th Aerodynamic Testing Conference, Bethesda, Md., July 8-10, 1974. Also, Journal of Aircraft, vol. 12, no. 6, June 1975, pp. 539-544, 4 refs.

AIAA Paper 74-631 A74-35395#

NASA has recently developed and proof tested a pilot cryogenic transonic pressure tunnel. In addition to providing an attractive method for obtaining high-Reynolds-number results at moderate aerodynamic loadings and tunnel power, this unique facility enables the independent determination of the effects of Reynolds number, Mach number, and aeroelasticity. The proof-of-concept experimental and theoretical studies are briefly reviewed. Experimental results are included on the pressure distributions for a two-dimensional airfoil and strain-gage balance characteristics for a three-dimensional, delta-wing model.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

16. *Polhamus, E. C.; *Kilgore, R. A.; *Adcock, J. B.; and *Ray, E. J.: **The Langley Cryogenic High Reynolds Number Wind-Tunnel Program.** Astronautics and Aeronautics, vol. 12, no. 10, October 1974, pp. 30-40, 16 refs.

N74-45305#

A pilot version of a new type of transonic tunnel was placed in operation in the fall of 1973. The tunnel uses the cryogenic concept to obtain a high Reynolds number. The cryogenic concept uses low temperatures to increase the Reynolds number by reducing the viscous forces rather than increasing the inertia forces. The cryogenic approach offers the desired Reynolds number increase with no increase in dynamic pressure. Therefore, no increase in model loads. A series of aerodynamic experiments have been made in the pilot tunnel to confirm the cryogenic concept at transonic speeds. This paper gives a brief description of the project for a large tunnel which has evolved from the studies.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

17. *Kilgore, R. A.; **Goodyer, M. J.; *Adcock, J. B.; and *Davenport, E. E.: **The Cryogenic Wind Tunnel Concept for High Reynolds Number Testing.** NASA TN D-7762, November 1974, 96 pp., 25 refs.

N75-12000#

Theoretical considerations indicate that cooling the wind-tunnel test gas to cryogenic temperatures will provide a large increase in Reynolds number with no increase in dynamic pressure, while reducing the tunnel drive-power requirements. We made studies to determine the expected variations of Reynolds number and other parameters over wide ranges of Mach number, pressure, and temperature, with due regard to avoiding liquefaction. We developed practical operational procedures in a low-speed cryogenic tunnel. Aerodynamic experiments in the low-speed tunnel demonstrated the theoretically predicted variations in Reynolds number and drive power. The continuous-flow fan-driven tunnel is shown to be particularly well suited to take full advantage of operating at cryogenic temperatures.

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**University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

18. *Kilgore, R. A.; *Adcock, J. B.; and *Ray, E. J.: **Simulation of Flight Test Conditions in the Langley Pilot Transonic Cryogenic Tunnel.** NASA TN D-7811, December 1974, 24 pp., 5 refs.

N75-12001#

This paper briefly reviews the theory and advantages of the cryogenic tunnel concept. The unique ability to vary temperature independently of pressure and Mach number allows large reductions in model loads and tunnel power. It also allows the independent determination of Reynolds number, Mach number, and aeroelastic effects on the aerodynamic characteristics of the model. Various combinations of Reynolds number and dynamic pressure are established to accurately represent flight variations of aeroelastic deformation with altitude changes. We studied the consequences of the thermal and caloric imperfections of the test gas under cryogenic conditions and found them to be insignificant for operating pressures up to 5 atm. This paper describes the characteristics of the NASA Langley Pilot Transonic Cryogenic Tunnel and the results of initial tunnel operation. Tests of a two-dimensional airfoil at a Mach number of 0.85 show identical pressure distributions for a chord Reynolds number of 8.6 million obtained first at stagnation pressure of 4.91 atm and a stagnation temperature of 322 K and then at a stagnation pressure of 1.19 atm and a stagnation temperature of 116.5 K.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

19. *Reubush, D. E.: **The Effect of Reynolds Number on Boattail Drag.** AIAA 13th Aerospace Sciences Meeting, Pasadena, Calif., January 20-22, 1975, 7 pp., 16 refs.

AIAA Paper 75-63 A75-18286#

A test has been made in the NASA Langley Pilot Transonic Cryogenic Tunnel to determine the effects of varying Reynolds number on boattail drag at subsonic speeds. Six boattailed cone-cylinder nacelle models were tested with the jet exhaust simulated by a cylindrical sting. Reynolds number was varied from about 2.6 to 132 million by changing model length and unit Reynolds number. Boattail pressure coefficient distributions show that increasing Reynolds number tends to make the pressure coefficients in the expansion region more negative and the pressure coefficients in the recompression region more positive. These two effects were compensating and as a result, there was little or no net effect of Reynolds number on the pressure drag of the isolated boattails.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

20. *Adcock, J. B.; *Kilgore, R. A.; and *Ray, E. J.: **Cryogenic Nitrogen as a Transonic Wind-Tunnel Test Gas.** AIAA 13th Aerospace Sciences Meeting, Pasadena, Calif., January 20-22, 1975, 9 pp., 6 refs.

AIAA Paper 75-143 A75-18341#

The test gas for the NASA Langley Pilot Transonic Cryogenic Tunnel is nitrogen. This paper reviews results from analytical and experimental studies which have verified cryogenic nitrogen as an acceptable test gas. Real-gas-isentropic and normal-shock-flow solutions for nitrogen are compared to the ideal diatomic gas solutions. Experimental data demonstrate that for temperatures above the liquefaction boundaries there are no significant real-gas effects on two-dimensional airfoil pressure distributions. Results of studies to determine the minimum operating temperatures while avoiding appreciable effects due to liquefaction are included.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

21. *Ray, E. J.; *Kilgore, R. A.; *Adcock, J. B.; and *Davenport, E. E.: **Analysis of Validation Tests of the Langley Pilot Transonic Cryogenic Tunnel.** NASA TN D-7828, February 1975, 22 pp., 4 refs.

N75-16569#

A Pilot Transonic Cryogenic Pressure Tunnel has recently been developed and proof tested at the NASA Langley Research Center. In addition to providing an attractive method for obtaining high-Reynolds-number results at moderate aerodynamic loading and tunnel power, this unique tunnel allows the independent determination of the effects of Reynolds number, Mach number, and dynamic pressure (aeroelasticity) on the aerodynamic characteristics of the model under test. The proof-of-concept experimental and theoretical studies are briefly reviewed. Experimental results obtained on both two- and three-dimensional models have substantiated that cryogenic test conditions can be set accurately and that cryogenic gaseous nitrogen is a valid test gas.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

22. *Osborne, B. P., Jr.; and **Nicks, O. W. (Co-chairmen): **National Transonic Facility: Report of the 1974 National Aeronautical Facilities Subpanel to the Aeronautics Panel, AACB.** Aeronautics and Astronautics Coordinating Board, Washington, DC, May 1975, 63 pp., 16 refs.

N79-79161#

At its 69th meeting, the Aeronautics and Astronautics Coordinating Board (AACB) authorized the Aeronautics Panel to proceed with a review of national aeronautics facilities. The specific Terms of Reference are set forth in Attachment A. The members of the 1974 National Aeronautics Facilities Subpanel constituted by the Aeronautics Panel are identified in Attachment B. Before the first meeting of the subpanel, the Co-chairmen of the AACB Aeronautics Panel agreed to modify the Terms of Reference to eliminate consideration by this subpanel of the USAF Aeropropulsion System Test Facility (ASTF) and the NASA Ames 40- by 80-Foot tunnel modifications. Hence, this report is concerned only with a review of the High-Reynolds-Number Tunnel (HiRT), the Transonic Research Tunnel (TRT), and related requirements.

*U.S. Department of Defense, Arlington, VA 20301 U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

23. *Kilgore, R. A.; and *Kuhn, R. E.: **Recent Progress on New Facilities at the NASA Langley Research Center.** In AGARD-CP-187, "Flight/Ground Testing Facilities Correlation," pp. 2-1 through 2-14, 17 refs. Presented at the 46th Meeting of the Flight Mechanics Panel, Valloire, France, June 9-13, 1975.

N76-25269#

A new fan-driven high-Reynolds-number transonic cryogenic tunnel is being planned for the United States. This tunnel is to be known as the National Transonic Facility. It will take full advantage of the cryogenic concept to provide an order of magnitude increase in Reynolds number capability over existing tunnels. Based on theoretical studies and experience with the NASA Langley 0.3-m Transonic Cryogenic Tunnel, the cryogenic concept has been shown to offer many advantages with respect to the attainment of full-scale Reynolds number at reasonable levels of dynamic pressure. The unique modes of operation available only in a cryogenic tunnel make possible for the first time the separation of Mach number, Reynolds number, and aeroelastic effects. By reducing the drive-power requirements to a level where we can use a conventional fan-drive system, the cryogenic concept makes possible a tunnel with high productivity and run times sufficiently long to allow for all types of tests. It does this at reduced capital costs and for equal amounts of testing, reduced total energy consumption in comparison with other tunnel concepts.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

24. *Hall, R. M.: **Preliminary Study of the Minimum Temperatures for Valid Testing in a Cryogenic Wind Tunnel.** NASA TM X-72700, August 1975, 125 pp., 4 refs.

N75-28078#

The minimum operating temperature which avoids real-gas effects such as condensation was determined at a Mach number of 0.85 for a 0.137-m NACA 0012-64 airfoil mounted in the NASA Langley 0.3-m Transonic Cryogenic Tunnel. For temperatures within 5 K of reservoir saturation and total pressures from 1.2 to 4.5 atm, the pressure distributions over the airfoil are not altered by real-gas effects. This ability to test at total temperatures below those which avoid saturation over the airfoil allows an increase in Reynolds-number capability of at least 17 percent for a constant tunnel total pressure. Similarly, 17-percent-less total pressure is required to obtain a given Reynolds number.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

25. *Mabey, D. G.: **Some Remarks on Dynamic Aeroelastic Model Tests in Cryogenic Wind Tunnels.** Presented at NASA Langley Research Center, September 1975, NASA CR-1145029, 39 pp., 1 ref.

N76-78044

The use of cryogenic wind tunnels to test dynamic aeroelastic models is the subject of this informal lecture and discussion. Emphasis is placed on buffet testing with a description of two semispan models which could be tested in the NASA Langley 0.3-m Transonic Cryogenic Tunnel to develop a buffet testing technique suitable for use at cryogenic temperatures.

*Royal Aircraft Establishment, Bedford, Beds MK41 6AE, England

26. *Reubush, D. E.: **The Effect of Reynolds Number on the Boattail Drag of Two Wing-Body Configurations.** 11th AIAA and SAE Propulsion Conference, Anaheim, Calif., September 29 - October 1, 1975, 8 pp., 18 refs.

AIAA Paper 75-1294 A75-45681#

Tests have been made in the NASA Langley 0.3-m Transonic Cryogenic Tunnel to determine the effects of varying Reynolds number on the boattail drag of wing-body configurations at subsonic speeds. Two boattailed cone-cylinder nacelle models were tested with a 60° delta wing at an angle of attack of 0°. Reynolds number, based on model length, was varied from about 2.5 to 67 million. Even though the presence of the wing has large effects on the boattail pressure coefficients, the results of this study were similar to those previously found for a series of isolated boattails. Boattail pressure coefficients in the expansion region became more negative with increasing Reynolds number, while those in the recompression region became more positive. These two effects were compensating; and, as a result, there was virtually no effect of Reynolds number on boattail pressure drag.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

27. *Hall, R. M.; and *Ray, E. J.: **Investigation of Minimum Operating Temperatures for Cryogenic Wind Tunnels.** AIAA 14th Aerospace Sciences Meeting, Washington, DC, January 26-28, 1976, 4 refs. Also, Journal of Aircraft, vol. 14, no. 6, June 1977, pp. 560-564.

AIAA Paper 76-89 A76-18781#

Total temperatures corresponding to the onset of condensation effects were determined for flow over a 0.137-m NACA 0012-64 airfoil mounted in the NASA Langley 0.3-m Transonic Cryogenic Tunnel. Tests were made at a total-pressure range from 1.2 to 4.5 atm and at free-stream Mach numbers of 0.75, 0.85, and 0.95. No condensation effects were found to occur until total temperatures were below those associated with free-stream saturation. Significant increases in Reynolds number may apparently be obtained by operation at temperatures below those associated with local saturation over the airfoil but above those where effects first occur. For the 0.85 and 0.95 Mach numbers, the increase in Reynolds number was at least 15 percent over those achieved at local saturation conditions for the same pressure range.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

28. *Ludwieg, H.; *Grauer-Carstensen, H.; and *Lorenz-Meyer, W.: **The Ludwieg Tube–A Proposal for a High Reynolds Number Transonic Wind Tunnel.** In AGARD-CP-174, Wind Tunnel Design and Testing Technology, March 1976, pp. 3-1 through 3-11, 19 refs.

N76-25216

After a brief review of the historical development of the Large European High-Reynolds-Number Tunnel (LEHRT) and its specifications, the advantages and flexibility of a Ludwieg tube drive system are outlined. Special emphasis is given to the development of the boundary layer in the charge tube and its influence on the flow quality in the test section. The theoretical predictions of boundary-layer growth are confirmed by experimental results. An improved prediction method for the turbulence in the test section is given. Means to affect the turbulence to meet the LEHRT requirements are outlined. After a short review of the development of cost estimates, some options are discussed which promise significant reduction in construction costs without impairing performance. These solutions are the use of prestressed concrete for large parts of the construction, lowering the stagnation temperature by an amount of approximately 50 °C, and operation at cryogenic temperatures.

*DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

29. *Kilgore, R. A.; *Adcock, J. B.; and *Ray, E. J.: **The Cryogenic Transonic Wind Tunnel for High Reynolds Number Research.** In AGARD-CP-174, Wind Tunnel Design and Testing Technology, March 1976, pp. 1-1 through 1-20, 27 refs.

N76-25214

Based on theoretical studies and experience with a low-speed cryogenic tunnel and a transonic cryogenic tunnel, the cryogenic wind-tunnel concept has been shown to offer many advantages with respect to the attainment of full-scale Reynolds number at reasonable levels of dynamic pressure in a ground-based facility. The unique modes of operation available in a pressurized cryogenic tunnel make possible for the first time the separation of Mach number, Reynolds number, and aeroelastic effects.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

30. *Haut, R. C.; and **Adcock, J. B.: **Steady Normal Shock Wave Solution Tables of Parahydrogen for Total Temperatures from 30 K to 290 K and for Total Pressure from 1 Atm to 10 Atm.** NASA TM X-73899, April 1976, 100 pp., 4 refs.

N76-23518#

The steady, normal shock-wave solutions of parahydrogen at various total pressures and total temperatures were numerically determined by iterating the upstream Mach number and by using a modified interval halving technique. The results obtained are compared with the ideal diatomic gas values and are presented in tabulated form.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

31. *Haut, R. C.; and **Adcock, J. B.: **Tables of Isentropic Expansions of Parahydrogen and Related Transport Properties for Total Temperatures from 25 K to 300 K and for Total Pressures from 1 Atm to 10 Atm.** NASA TM X-72826, April 1976, 93 pp., 6 refs.

N76-22489#

The isentropic expansions of parahydrogen at various total pressures and total temperatures were numerically determined by iterating Mach number and by using a modified interval halving method. The calculated isentropic values and related properties are presented in tabulated form.

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**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

32. *Reubush, D. E.; and *Putnam, L. E.: **An Experimental and Analytical Investigation of Effect on Isolated Boattail Drag of Varying Reynolds Numbers up to 130,000,000.** NASA TN D-8210, May 1976, 85 pp., 26 refs.

N76-23171#

A study was made to determine whether large Reynolds number effects occur on isolated boattails. The study included an analytical study and test in the NASA Langley 0.3-m Transonic Cryogenic Tunnel. This tunnel test was made at an angle of attack of 0° at Mach numbers from 0.6 to 0.9 for Reynolds numbers up to 130 million. Results indicate that as the Reynolds number is increased, the boattail static pressure coefficients in the expansion region become more negative while those in the recompression region become more positive. These two trends are compensating and, as a result, there is only a small effect (if any) of Reynolds number on boattail pressure drag.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

33. *Rao, D. M.: **Wind Tunnel Design Studies.** Final report (June 1975 through May 1976). Old Dominion Univ., TR-76-T11, NASA CR-148149, May 1976, 31 pp., 8 refs.

N76-25156#

This report describes work at the NASA Langley Research Center in support of the U.S. National Transonic Facility Project Office. The report is in three parts: estimation of aerodynamic losses in the tunnel circuit, 2nd-turn model studies, and proposed circuit modification for LN_2 economy and shell cost savings. The report emphasizes the basic motivation behind the problems studied and gives the main results and conclusions obtained.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.
NASA Grant NSG-1135

34. *Bremen, K. W.: **Models for a Cryogenic Wind Tunnel With 3.2 m² Test Section; Stagnation Pressure 4-6 Bars.** National Aerospace Lab. NLR Memo-TP-76-008, June 2, 1976, 6 pp.

N81-73773

This note gives some comments on the feasibility of wind-tunnel models to be used under cryogenic conditions. The matters discussed are (a) materials, (b) design, and (c) model handling. Finally, the conclusion is given that no major problems are expected.

*National Aerospace Laboratory, 1006 BM Amsterdam, The Netherlands

35. *Schoenmakers, T. J.: **Strain Gauge Balances for a Cryogenic Wind Tunnel With 3.2 m² Test Section and Stagnation Pressure of 4 to 6 Bars.** National Aerospace Lab. NLR-Memo-TP-76-007, June 2, 1976, 5 pp.

N81-73903

This paper presents remarks on the feasibility of using strain-gauge balances in a cryogenic wind tunnel with a 3.2 m² test section and stagnation pressures of 4 to 6 bars. These comments are based on a short study and on discussions within the department of the NLR responsible for the development of strain-gauge balances for the existing wind tunnels. Problems induced by the low temperatures are expected to be resolvable by executing an appropriate development program; high aerodynamic loads may put some limitations to testing relatively slender bodies.

*National Aerospace Laboratory, 1006 BM Amsterdam, The Netherlands

36. *McKinney, L. W.; and *Howell, R. R.: **The Characteristics of the Planned National Transonic Facility.** AIAA 9th Aerodynamic Testing Conference held in Arlington, Tex., June 7-9, 1976. In: A76-38626 (pp. 176-184), 18 refs.

A76-38645#

The U.S. National Transonic Facility is a high-Reynolds-number transonic wind tunnel designed to satisfy the research and development needs of NASA, DoD, and industry. The tunnel design incorporates the cryogenic approach to achieving high Reynolds numbers with manageable model loads. By using temperature as a test variable, a unique capability to separate aeroelastic, Reynolds number, and Mach number effects will be possible. This capability will open new horizons in transonic aerodynamic research. The tunnel design, including unique features and operating envelopes, is described. A brief overview of the general operating arrangement and the schedule for facility construction is presented.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

37. *Kilgore, R. A.; and *Davenport, E. E.: **Static Force Tests of a Sharp Leading Edge Delta-Wing Model at Ambient and Cryogenic Temperatures With a Description of the Apparatus Employed.** NASA TM X-73901, June 1976, 50 pp., 14 refs.

N76-28159#

We tested a sharp leading-edge delta-wing model through an angle-of-attack range at Mach numbers of 0.75, 0.80, and 0.85 at both ambient and cryogenic temperatures in the NASA Langley 0.3-m Transonic Cryogenic Tunnel. We varied total pressure with total temperature to hold test Reynolds number constant at a given Mach number. Agreement between the aerodynamic data obtained at ambient and cryogenic temperatures indicates flows with leading-edge vortex effects are duplicated properly at cryogenic temperatures. The test results demonstrate we can obtain accurate aerodynamic data using conventional force-testing techniques if we take suitable measures to minimize temperature gradients across the balance and keep the balance at ambient (warm) temperatures during cryogenic operation of the tunnel.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

38. *Lambourne, N. C.: **Similarity Requirements for Flutter and Other Aeroelastic Models in a Cryogenic Wind Tunnel.** RAE-TMStruct-888, June 1976, 13 pp.

N77-19083#

A consideration of the requirements for aeroelastic similarity shows that the low working temperature of a cryogenic tunnel and an ability to vary temperature both have potential advantages in regard to the choice of suitable stiffness and density scales for an aeroelastic model. The advantages are incidental to the main purpose of a cryogenic tunnel, to achieve high Reynolds numbers.

*Royal Aircraft Establishment, Bedford, Beds MK41 6AE, England

39. *Hall, R. M.: **Cryogenic Wind Tunnels: Unique Capabilities for the Aerodynamicist.** Presented at the 54th Annual Meeting of the Virginia Academy of Science, July 1976. NASA TM X-73920, 16 pp., 7 refs.

N76-27252#

The cryogenic wind-tunnel concept is a practical means for improving ground simulation of transonic flight conditions. The NASA Langley 0.3-m Transonic Cryogenic Tunnel is operational and the design of a cryogenic National Transonic Facility is undertaken. A review of some of the unique capabilities of cryogenic wind tunnels is presented. In particular, the advantages of having independent control of tunnel Mach number, total pressure, and total temperature are highlighted. This separate control over the three tunnel parameters will open new frontiers in Mach number, Reynolds number, aeroelastic, and model-tunnel interaction studies.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

40. *Reubush, D. E.: **Effect of Reynolds Number on the Subsonic Boattail Drag of Several Wing-Body Configurations.** NASA TN D-8238, July 1976, 84 pp.

N76-26157#

A test was made in the 0.3-m Transonic Cryogenic Tunnel to determine the effect of varying Reynolds number on the boattail drag of several wing-body configurations. Tests were made at 0° angle of attack at Mach numbers from 0.6 to 0.9 for Reynolds numbers up to 67 million (based on distance from the nose to the start of the boattail). Results indicate as the Reynolds number is increased the boattail static pressure coefficients in the expansion region of the boattail become more negative while those in the recompression region become more positive. Results show there is only a small effect of Reynolds number on boattail pressure drag.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

41. *Mabey, D. G.: **Some Remarks on the Design of Transonic Tunnels With Low Levels of Flow Unsteadiness.** NASA CR-2722, August 1976, 19 pp., 41 refs. (Based on a lecture given at NASA Langley on September 15, 1975.)

N79-25039#

This paper defines flow unsteadiness in wind tunnels and outlines its importance for aerodynamic measurement. The principal sources of flow unsteadiness in the circuit of a transonic wind tunnel are listed. We must take care to avoid flow separations, acoustic resonances, and large-scale turbulence. Some problems discussed are the elimination of diffuser separations, the aerodynamic design of coolers, and the unsteadiness generated in ventilated working sections (both slotted and perforated).

*Royal Aircraft Establishment, Bedford, Beds MK41 6AE, England

42. *Hall, R. M.: **An Analysis of Data Related to the Minimum Temperatures for Valid Testing in Cryogenic Wind Tunnels Using Nitrogen as the Test Gas.** NASA TM X-73924, August 1976, 110 pp., 5 refs.

N76-29269#

The minimum operating temperature which avoids adverse low-temperature effects, such as condensation, has been determined at a free-stream Mach number of 0.85 for flow over a 0.137-m airfoil mounted at zero incidence in the NASA Langley 0.3-m Transonic Cryogenic Tunnel. The onset of low-temperature effects is established by comparing the pressure coefficient measured at a given orifice for a particular temperature with those measured at temperatures sufficiently above where low-temperature effects might be expected to occur. The pressure distributions over the airfoil are presented in tabular form. In addition, the comparisons of the pressure coefficients as a function of total temperature are presented graphically for chord locations of 0, 25, 50, and 75 percent. Over the 1.2 to 4.5 atm total-pressure range studied, low-temperature effects are not detected until total temperatures are 2 K, or more, below free-stream saturation temperatures.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

43. *Reubush, D. E.: **Experimental Investigation to Validate Use of Cryogenic Temperatures to Achieve High Reynolds Numbers in Boattail Pressure Testing.** NASA TM X-3396, August 1976, 35 pp., 13 refs.

N76-30228#

A test was made in the NASA Langley 0.3-m Transonic Cryogenic Tunnel to validate the use of cryogenic temperatures to achieve high Reynolds numbers in nozzle boattail pressure testing. Tests were made at 0° angle of attack and at Mach numbers of 0.60, 0.85, and 0.90 on two wing-body configurations with differing boattail geometries. Test data were obtained by using two different techniques, the cryogenic method and the conventional method, to obtain the same Reynolds number. Later, the test data obtained from the two techniques on boattail pressure coefficient distributions and pressure drag coefficients were compared. The results from the comparisons show excellent repeatability for all test conditions. They indicate no measurable errors when using cryogenic temperatures to achieve high Reynolds number for nozzle boattail pressure testing.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

44. Goethert, B. H.: **Technical Evaluation Report on the Fluid Dynamics Panel Symposium on Wind Tunnel Design and Testing Techniques.** AGARD-AR-97, August 1976, 23 pp.

N76-30236#

Advanced wind-tunnel systems are discussed with emphasis on the impact of the cryogenic concept for high-performance transonic wind tunnels. Topics covered include cryogenic operation, adjustable walls, magnetic suspensions, and laser instrumentation.

45. *Haut, R. C.; and **Adcock, J. B.: **Prandtl-Meyer Flow Tables for Parahydrogen at Total Temperatures from 30 K to 290 K and for Nitrogen at Total Temperatures from 100 K to 300 K at Total Pressures from 1 Atm to 10 Atm.** NASA TM X-73932, August 1976, 194 pp.

N76-30497#

The dependency of Mach number on the Prandtl-Meyer function was numerically determined by iterating the Prandtl-Meyer function and applying the Muller method to converge on the Mach number for flows in cryogenic parahydrogen and nitrogen at various total pressures and total temperatures. The results are compared with the ideal diatomic gas values and are presented in tabular form.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

46. *Howell, R. R.; and *McKinney, L. W.: **The U.S. 2.5-Meter Cryogenic High Reynolds Number Tunnel.** 10th ICAS Congress, Ottawa, Canada, October 3-8, 1976, 12 pp., 11 refs.

ICAS Paper 76-04 A76-47353#

The U.S. 2.5-Meter Cryogenic High-Reynolds-Number Tunnel is a fan-driven transonic wind tunnel scheduled for operation in 1981. It will operate at Mach numbers from 0.1 to 1.2, stagnation pressures from 1 to 9 bars, and stagnation temperatures from 352 to 80 K. The maximum Reynolds number capability will be 120 million at a Mach number of 1.0 based on a reference length of 0.25 m. This paper describes the basis for the conceptual approach, the engineering design including unique features, and the performance operating envelopes for the tunnel.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

47. *Nicks, O. W.: **The NTF as a National Facility.** In: "High Reynolds Number Research," NASA CP-2009, 1977, (N77-27139, pp. 19-51, 11 refs.), a workshop held at NASA Langley, October 27-28, 1976.

N77-27141#

Note: For the complete workshop see citation no. [76] in this bibliography.

Activities which led to the definition of the U.S. National Transonic Facility and the general agreements reached regarding its use and operations are reviewed. Topics discussed include redefinition of test requirements, development of low-cost options, consideration of a single transonic facility using existing hardware if feasible, facility concept recommendations, and acquisition schedule proposals.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

48. *Kilgore, R. A.: **Cryogenic Wind-Tunnel Technology.** In: "High Reynolds Number Research," NASA CP-2009, 1977, (N77-27139, pp. 53-63, 5 refs.), a workshop held at NASA Langley, October 27-28, 1976.

N77-27142#

Note: For the complete workshop see citation no. [76] in this bibliography.

After a brief review of the cryogenic concept, this paper presents some of the aspects which must be considered during the development of a cryogenic wind tunnel that uses nitrogen as the test gas. Even though the values of the compressibility factor and the ratio of specific heats of nitrogen depart significantly from their ideal-gas values at cryogenic temperatures, both the isentropic flow parameters and the normal-shock flow parameters are insignificantly affected by these real-gas effects. It is possible to operate at stagnation temperatures even lower than those corresponding to the free-stream saturation boundary without encountering condensation effects. Should this mode of operation be possible, we can realize an additional increase in Reynolds number of about 17 percent at a given operating pressure. Alternatively, for a given Reynolds number, operating at the free-stream saturation boundary temperature allows testing at reduced pressure, drive power, and liquid nitrogen consumption.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

49. *Gillespie, V. P.: **The Design of Models for Cryogenic Wind Tunnels.** In: "High Reynolds Number Research," NASA CP-2009, 1977, (N77-27138, pp. 73-79), a workshop held at NASA Langley, October 27-28, 1976.

N77-27144#

Note: For the complete workshop see citation no. [76] in this bibliography.

Factors to be considered in designing and building models for transonic cryogenic wind tunnels operating at high pressure include high-model loads imposed by the high-operating pressures, the mechanical and thermodynamic properties of materials in low-temperature environments, and the combination of aerodynamic loads with the thermal environment. Candidate materials are being studied to establish criteria for cryogenic wind-tunnel models and their installation. Data acquired from these tests will be provided to users of the U.S. National Transonic Facility.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

50. *Guarino, J. F.: **Instrumentation and Data Acquisition Systems.** In: "High Reynolds Number Research," NASA CP-2009, 1977, (N77-27139, pp. 81-101, 3 refs.), a workshop held at NASA Langley, October 27-28, 1976.

N77-27145#

Note: For the complete workshop see citation no. [76] in this bibliography.

A comprehensive and integrated measurement system was identified and a design and development effort initiated to meet the criteria imposed by the U.S. National Transonic Facility (NTF) operating environment. Specific measurement areas receiving concentrated attention include data acquisition, force measurement, pressure instrumentation, flow-visualization techniques, model attitude and model deformation measurement, and temperature measurement. The NTF instrument complex will be centered around four 32-bit, 1-micro-second-cycle-time central processing units connected in a multipoint-distributed network configuration. The principle activities to be supported by these computers are (1) data base management and processing, (2) research measurement data acquisition and display, (3) tunnel and model control, and (4) process monitoring and communication control. The distributed network approach was chosen to modularize the functional software into definable and implementable parts by the various groups involved in the design and to permit use of similar hardware configurations to improve reliability and maintainability.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

51. *Kilgore, R. A.: **The Cryogenic Wind Tunnel.** In: NASA CP-2001, Advances in Engineering Science, Vol. 4, 1976, (N77-10345#, pp. 1565-1581, 21 refs.). Presented at the 13th Annual Meeting of the Society of Engineering Science, Hampton, Va., November 1-3, 1976.

N77-10368#

Based on theoretical studies and experience with a low-speed cryogenic tunnel and with a 0.3-meter transonic cryogenic tunnel, the cryogenic wind-tunnel concept offers many advantages with respect to the attainment of full-scale Reynolds number at reasonable levels of dynamic pressure. The unique modes of operation available in a pressurized cryogenic tunnel make possible for the first time the separation of Mach number, Reynolds number, and aeroelastic effects. By reducing the drive-power requirements to a level where we can use a conventional fan-drive system, the cryogenic concept makes possible a tunnel with high productivity and run times sufficiently long to allow for all types of tests. It does this at reduced capital costs and, for equal amounts of testing, reduced total energy consumption in comparison with other tunnel concepts.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

52. *Baals, D. D.: **Design Considerations of the National Transonic Facility.** In: NASA CP-2001, Advances in Engineering Science, Vol. 4, 1976, (N77-10345#, pp. 1583-1602, 13 refs.) Presented at the 13th Annual Meeting of the Society of Engineering Science, Hampton, Va., November 1-3, 1976.

N77-10369#

The inability of existing wind tunnels to provide aerodynamic test data at transonic speeds and flight Reynolds numbers is examined. The proposed transonic facility is a high-Reynolds-number transonic wind tunnel designed to meet the research and development needs of government and the academic community. The tunnel uses the cryogenic approach to achieve high Reynolds numbers at acceptable model loads and tunnel power. By using temperature as a test variable, a unique capability to separate scale effects from model aeroelastic effects is provided. The performance envelope of the facility is shown to provide a ten-fold increase in transonic Reynolds number capability compared to currently available facilities.

*Joint Institute for Advancement of Flight Sciences, George Washington University, NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

53. *Kilgore, R. A.: **Design Features and Operational Characteristics of the Langley 0.3-Meter Transonic Cryogenic Tunnel.** NASA TN D-8304, December 1976, 51 pp., 16 refs. (This document was previously published as NASA TM X-72012, 1974.)

N77-12071#

Experience with the fan-driven 0.3-m Transonic Cryogenic Tunnel (TCT) indicated such a tunnel presents no unusual design difficulties and is simple to operate. Purging, cooldown, and warmup times are acceptable and are predicted with good accuracy. Cooling with liquid nitrogen is practical over a wide range of operating conditions at power levels required for transonic testing. Good temperature distributions are obtained using a simple liquid nitrogen injection system. To take full advantage of the unique Reynolds number capabilities of the 0.3-m TCT, we designed it to accommodate test sections other than the original, octagonal, three-dimensional test section. A 20- by 60-cm two-dimensional test section was recently installed and is being calibrated. A two-dimensional test section with self-streamlining walls and a test section using a magnetic suspension and balance system are being considered.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

54. *Stallings, R. L., Jr.; and *Lamb, M.: **A Simplified Method for Calculating Temperature Time Histories in Cryogenic Wind Tunnels.** NASA TM X-73949, December 1976, 16 pp., 5 refs.

N77-13076#

Average temperature time-history calculations of the test gas and tunnel walls for cryogenic wind tunnels have been developed. Results are in general agreement with limited preliminary experimental measurements obtained in a 13.5-in. pilot cryogenic wind tunnel.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

55. *Adcock, J. B.: **Real-Gas Effects Associated With One-Dimensional Transonic Flow of Cryogenic Nitrogen.** NASA TN D-8274, December 1976, 272 pp., 10 refs.

N77-15345#

Real-gas solutions for one-dimensional isentropic and normal-shock flows of nitrogen were obtained for a wide range of temperatures and pressures. These calculations are compared to ideal-gas solutions and are presented in tables. For temperatures (300 K and below) and pressures (1 to 10 atm) that cover those anticipated for transonic cryogenic tunnels, the solutions are analyzed to obtain indications of the magnitude of inviscid-flow-simulation errors. For these ranges, the maximum deviation of the various isentropic and normal shock parameters from the ideal values is about 1 percent or less; which, for most wind-tunnel studies, is insignificant.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

56. *Wagner, B.; and *Schmidt, W.: **Theoretical Investigations of Real Gas Effects in Cryogenic Wind Tunnels, Final Report.** DS-FB-76/50B, December 1976, 82 pp., 18 refs.

N79-17820#

Real-gas effects in cryogenic nitrogen flows were calculated using the Beattie-Bridgeman equation of state. The studies include Prandtl-Meyer expansions, oblique shocks, transonic small perturbation theory, transonic flow past an NACA 0012 aerofoil, and shock boundary layer interaction. The last two cases mentioned were treated with the aid of finite-volume techniques.

*Dornier GmbH–Friedrichshafen 1, Postfach 1420, D-7990 Friedrichshafen 1, FRG

57. *Hartzuiker, J. P.: **The Proposed Cryogenic European Transonic Windtunnel (ETW).** Nederlandse Vereniging voor Luchtvaartechniek, Yearbook 1977, 1978, pp. 1.1-1.21. Based on a lecture presented to the Netherlands Association of Aeronautical Engineers, January 20, 1977.

A79-17118#

The proposed European Transonic Windtunnel is described: a cryogenic tunnel with test-section dimensions compatible with existing major European transonic tunnels. Reynolds number based on mean aerodynamic chord lies between 25 and 40 million. The advantages and drawbacks of cryogenic testing, as well as fundamental aspects of cryogenic aerodynamics, are discussed. Comparative estimates for capital and operating costs are presented.

*National Aerospace Laboratory, 1006 BM Amsterdam, The Netherlands

58. **National Transonic Facility Environmental Impact Statement, Final Amendment 1.** NASA TM-79372, January 1977, 188 pp.

N80-71996

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*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

59. *Kilgore, R. A.; and *Adcock, J. B.: **Specific Cooling Capacity of Liquid Nitrogen.** NASA TM X-74015, February 1977, 19 pp., 10 refs.

N77-21261#

Most cryogenic wind tunnels are cooled by injecting liquid nitrogen directly into the tunnel. The specific cooling capacity of the nitrogen consists of the heat absorbed in warming and vaporizing the liquid plus the heat absorbed in warming the gaseous nitrogen to the tunnel stagnation temperature. We calculated the specific cooling capacity of nitrogen for a simplified model based on this method of cooling using a National Bureau of Standards program for the thermodynamic properties of nitrogen. We fitted the results with a relatively simple equation having tunnel stagnation pressure and stagnation temperature as the independent variables. This report describes the assumed cooling process and the method used to calculate the specific cooling capacity of liquid nitrogen. It also gives the simple equation fitted to the calculated specific cooling capacity data. Finally, it gives in graphical form calculated values of the specific cooling capacity of nitrogen for stagnation temperatures from saturation to 350 K and stagnation pressures from 1 to 10 atm.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

60. *Adcock, J. B.; and *Ogburn, M. E.: **Power Calculations for Isentropic Compressions of Cryogenic Nitrogen.** NASA TN D-8389, March 1977, 15 pp., 9 refs.

N77-20378#

Note: Formerly published as NASA TM X-73903 (N76-28516#), July 1976.

We have made a theoretical analysis of the power required for isentropic compressions of cryogenic nitrogen to determine the extent that the drive power for cryogenic tunnels might be affected by real-gas effects. The analysis covers temperatures from 80 to 310 K, pressures from 1.0 to 8.8 atm and fan-pressure ratios from 1.025 to 1.200. The power required to compress cryogenic nitrogen was found to be lower than that required for an ideal diatomic gas by as much as 9.5 percent. Simple corrections to the ideal-gas values were found to give accurate estimates of the real-gas power values.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
NASA Grant NSG-1010

61. *Wagner, B.; and *Schmidt, W.: **Theoretische Untersuchungen zur Stoss-Grenzschicht-Wechselwirkung in kryogenem**

Stickstoff. (Theoretical Studies on the Shock Wave-Boundary Layer Interaction in Cryogenic Nitrogen.) In: Contributions on Transport Phenomena in Fluid Mechanics and Related Topics, Tech. Univ. Berlin, April 12, 1977, pp. 277-287, 15 refs., in German. Also, Zeitschrift fur Flugivissenschaften und Weltraumforschung, vol. 2, no. 2, March-April 1978, pp. 81-88, 15 refs., in German.

N77-12402#
A77-47972#
A78-34159

Note: For an English translation see citation no. [94] in this bibliography.

*Dornier GmbH–Friedrichshafen 1, Postfach 1420, D-7990 Friedrichshafen 1, FRG

62. *Haut, R. C.: **Evaluation of Hydrogen as a Cryogenic Wind Tunnel Test Gas. Final Report.** NASA CR-145186, April 1977, 159 pp., 28 refs. A synopsis of this report is in the Journal of Aircraft, vol. 14, no. 12, December 1977, pp. 1155-1156, 6 refs. (This NASA CR is based on the Ph.D. thesis submitted to O.D.U.)

N77-24153#

The nondimensional ratios used to describe various flow situations in hydrogen were determined and compared with the corresponding ideal diatomic gas ratios. The results were used to examine different inviscid-flow configurations. The relatively high value of the characteristic rotational temperature causes the behavior of hydrogen, under cryogenic conditions, to deviate substantially from the behavior of an ideal diatomic gas in the compressible-flow regime. Therefore, if an ideal diatomic gas is to be modeled, cryogenic hydrogen is unacceptable as a wind-tunnel gas in a compressible-flow situation.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.
NASA Grant NGR-47-003-052

63. *Voth, R. O.; and *Strobridge, T. R.: **Cryogenic Design and Safety Review-NASA-Langley Research Center 0.3-Meter Transonic Cryogenic Tunnel.** NASA TM-74767; NBSIR-77-857, April 1977, 28 pp., 3 refs.

N77-28143#

A cryogenic design and safety review of the 0.3-m Transonic Cryogenic Tunnel is presented. The tunnel working fluid and coolant is nitrogen. The nitrogen, supplied as liquid, is exhausted as a low-temperature gas. The tunnel and ancillary systems are generally well designed but several recommendations to improve the cryogenic systems are made. The cost of recovering the cold vent gas is compared to the cost of producing the required liquid nitrogen using a captive air separation plant. Although the economic analysis is preliminary, it shows that because of the periodic operation of the tunnel, a captive air separation plant has a lower annual operating cost than the vent gas recovery systems considered.

*National Bureau of Standards, Boulder Laboratories, Boulder, CO 80302 U.S.A.

64. *Wagner, B.; and *Schmidt, W.: **Theoretical Investigation of Real Gas Effects in Cryogenic Windtunnels.** Presented at the AIAA 10th Fluid and Plasmadynamics Conference, Albuquerque, N. Mex., June 27-28, 1977, 12 pp., 23 refs. Also, AIAA Journal, vol. 16, no. 6, June 1978, pp. 380-386.

AIAA Paper 77-669 A77-37023#

Real-gas effects in cryogenic nitrogen flows were calculated using the Beattie-Bridgeman equation of state. The studies include Prandtl-Meyer expansions, oblique shocks, transonic small perturbation theory, transonic flow past an NACA 0012 aerofoil, and shock-boundary-layer interaction. The two last cases mentioned have been treated with the aid of finite-volume techniques. The results show some noticeable deviations from the behavior of an ideal gas not only at cryogenic conditions but also at normal temperatures and high pressures. The deviations remain very small within the operating range of cryogenic wind tunnels if suitable reference quantities are used. Only the friction coefficient exhibits some systematic variation of considerable amount.

*Dornier GmbH–Friedrichshafen 1, Postfach 1420, D-7990 Friedrichshafen 1, FRG

65. *Adcock, J. B.: **Effect of LN_2 Injection Station Location on the Drive Fan Power and LN_2 Requirements of a Cryogenic Wind Tunnel.** NASA TM X-74036, June 1977, 19 pp., 5 refs.

N77-27137#

This paper presents a theoretical analysis comparing the fan power and coolant (LN_2) flow rates resulting from injection of the LN_2 either upstream or downstream of the drive fan of a closed-circuit transonic cryogenic tunnel. The analysis is restricted to steady-state tunnel operation and to the condition that the tunnel walls are adiabatic. The stagnation pressure and temperature range of the tunnel is from 1.0 to 8.8 atm and from 300 K to liquefaction temperature, respectively. Calculations are made using real-gas properties of nitrogen. Results show the fan power and LN_2 flow rates are lower if the LN_2 is injected upstream of the fan. The lower fan inlet temperature resulting from injecting upstream of the fan has a greater influence on the power than does the additional mass flow going through the fan.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

66. *Lorenz-Meyer, W.: **Uber einige Moelichkeiten zur Berechnung des aehnlichkeitsparameters k* bei Realen Gasen.** In: "Contribution to Steady and Unsteady Aerodynamics," August 1977, pp. 189-201, 17 refs. For translation, see NASA TM-75222, **A Few Ways of Calculating the Similarity Parameter k* for Real Gases**, 13 pp.

N78-17017#, in German
N78-14121#, in English

The similarity parameter is referred to in connection with the question on the applicability of test results obtained from cryogenic wind tunnels to the large-scale model. A simple method is given for calculating the similarity parameter. From the numerical values obtained, we can deduce nitrogen behaves practically like an ideal gas when it is close to the saturation point and in a pressure range up to 4 bars. The influence of this parameter on the pressure distribution of a supercritical profile confirms this finding.

*DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

67. *Buongiorno, C.: **La Galleria Transonica Intermittente Criogenica per Gli Altissimi Numeri di Reynolds. (Cryogenic**

Intermittent Transonic Wind Tunnel for Very High Reynolds Numbers.) Presented at the 4th National Congress of the Italian Association of Aeronautics, Milan, Italy, September 19-23, 1977, 21 pp., in Italian.

N78-49739

The status of U.S. and European studies on a very high-Reynolds-number transonic wind tunnel is reviewed and a tunnel to be used by the Italian Aerospace Industries is proposed in the form of a transonic wind tunnel that makes use of both blowdown and cryogenic technology. The proposed wind tunnel measures 1 × 1.2 m and has the following characteristics: Reynolds number – 30 million, Mach number – 0.8-1.2, total temperature – 120 K, and total pressure – 520 KPa. Use of a sleeve valve significantly reduces turbulence intensity in the test section compared to the values normally obtained in a continuous wind tunnel. The air temperature is reduced to the desired stagnation temperature in an economical way through use of a regeneration heat exchanger. The relative low cost of the facility is given and its complementary use with the proposed European cooperative transonic wind tunnel (ETW) is discussed.

*Università di Roma la Sapienza, Via Eudossiana 16, I-00184 Roma, Italy

68. *Christophe, J.: **Genese du Projet de Soufflerie Transsonique Europeenne a Grand Nombre de Reynolds. (Genesis of the European High-Reynolds-Number Transonic Wind Tunnel Project).** Presented at the Association Aeronautique et Astronautique de France, 14th Colloque d'Aerodynamique Appliquee, Toulouse, France, November 7-9, 1977. Also: L'Aeronautique et l'Astronautique, no. 72, 1978, pp. 21-34, 40 refs., in French.

A79-17769

The proposed cryogenic wind-tunnel project, which would involve cooperation by Germany, France, The Netherlands, and the United Kingdom, is described. Reasons for performing high-Reynolds-number experiments are discussed and examples of proposed problems and their analyses are examined. Reasons for selecting the cryogenic design are considered with attention to the history of the wind-tunnel project and the performance of pilot-study wind tunnels.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

69. *Faulmann, D.; *Prieur, J.; and *Vergnolle, J. F.: **Essais Preliminaires sur une Installation Transsonique Fonctionnant par Rafales Cryogeniques. (Preliminary Tests of an Intermittent Transonic Cryogenic Tunnel).** Association Aeronautique et Astronautique de France, AAAF-NT-78-26, 15 pp., 1 ref. Presented at the 14th Colloque d'Aerodynamique Appliquee, Toulouse, France, November 7-9, 1977. Available NTIS and CEDOCAR, Paris, in French.

N79-23040#

To achieve in-flight Reynolds numbers, a preliminary system operative at low temperatures for a short period in a transonic wind tunnel is discussed and evaluated. Injection of liquid nitrogen at a point in the fluid circuit rapidly induces low temperatures for a test period on the order of 10 seconds. This technique of increasing the Reynolds number without introducing severe instrumentation problems (as is the case with continuous cryogenic systems) permits adaptation of existing transonic wind tunnels to an extended Reynolds number range. Since it was not possible to reduce the main circulation temperature below 200 K, an induction system with primary air cooled to 80 K was also tried with negative results.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

70. *Christophe, J.: **Projet de Soufflerie Transsonique Europeenne à Grand Nombre de Reynolds. (Transonic European Wind Tunnel Project for High Reynolds Numbers.)** Association Aeronautique et Astronautique de France, AAAF-NT-78-01. Presented at the 14th Colloque d'Aerodynamique Appliquee, Toulouse, France, November 7-9, 1977, 34 pp., 69 refs. Available NTIS and CEDOCAR, Paris, in French.

N79-23118#

Work from 1968 to the final joint recommendation to build a cryogenic transonic high-Reynolds-number wind tunnel for European governments is discussed. Such a project is necessary since actual flight performance differs from low-Reynolds-number transonic wind-tunnel results. Several alternatives were proposed and experimentally tried in pilot tests. The cryogenic solution was finally recommended as static pressure and power can be kept low for the same Reynolds number. The proposed wind tunnel is 1.95 × 1.65 m square, with maximum pressure at 4.4 bars, minimum temperature at 120 K, Mach number up to 1.35, and Reynolds number up to 40 million when working with cryogenic nitrogen.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

71. *Dupriez, F.: **Similtude, Realisation, Identification et Instrumentation des Maquettes d'Essais. (Similitude, Manufacturing, Identification, and Instrumentation of Test Models.)** Association Aeronautique et Astronautique de France, AAAF-NT-78-24, 38 pp., 4 refs. Presented at the 14th Colloque d'Aerodynamique Appliquee, Toulouse, France, November 7-9, 1977. Available NTIS and CEDOCAR, Paris, in French.

N79-23120#

Several aspects of present aircraft model technology are surveyed. Similitude and practical choice rules are discussed as well as identification and instrumentation techniques. Specifications and manufacturing are illustrated with several practical examples, such as use of high-technology composite materials (carbon and boron fibers); increasing use of numerical control manufacturing techniques, the rapid development of microprocessor use; and adaptation to basic technological changes such as cryogenic wind tunnels.

*University of Science & Technology, Lille, France

72. *Bazin, M.: **Problemes de Construction de Maquettes pour les Souffleries à Grand Nombre de Reynolds. (Construction Problems for Models for High Reynolds Number Wind Tunnels.)** Association Aeronautique et Astronautique de France, AAAF-NT-78-02. ONERA-NT-1978-6, 45 pp., 60 refs. Presented at the 14th Colloque d'Aerodynamique Appliquee, Toulouse, France, November 7-9, 1977. Available NTIS and CEDOCAR, Paris, in French.

N79-23124#

Note: For an abstract in English, see the following citation in this bibliography.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

73. *Bazin, M.: **Problems of Constructing Models for High Reynolds Number Wind Tunnels.** Association Aeronautique et Astronautique de France. Presented at the 14th Colloque d'Aerodynamique Appliquee, Toulouse, France, November 7-9, 1977. Available NTIS and CEDOCAR, Paris, in French. European Space Agency, Paris, France Rep. no. ESA-TT-564, June 1979, 50 pp., 60 refs.

N80-12101#

Note: For the original French version of this paper, see the preceding citation in this bibliography.

Design structures, problems of definition, and materials for high-Reynolds-number wind-tunnel models are discussed. Models for force and pressure distributions, air intakes, jet simulation, and dynamic flutter are considered. It is shown that deformations in operation under the effect of aerodynamic and thermal loads require new measuring techniques and the adaptation of the capacity, thermal protection, and calibration methods of the balance. The mechanical strength of the supports, in particular the risk of divergence and the dynamic behavior of the mountings, is the most severe limitation in the use of pressurized wind tunnels. Thermal problems are added in a cryogenic environment. The development of pressure measurement methods and instruments is considered.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

74. *Stollery, J. L.; and **Murthy, A. V.: **An Intermittent High-Reynolds-Number Wind Tunnel.** Aeronautical Quarterly, vol. 28, (A78-20193), November 1977, pp. 259-264, 4 refs. Also presented at the AIAA 10th Aerodynamic Testing Conference, San Diego, Calif., April 19-21, 1978, and at the 11th ICAS Congress, Lisbon, Portugal, September 10-16, 1978. In: Proceedings, vol. 1, (A79-20116#), pp. 461-465, 4 refs.

AIAA Paper 78-766 A78-32327#

This paper suggests a simple method of generating intermittent reservoir conditions for an intermittent cryogenic wind tunnel. This can be done by operating some existing types of short-duration tunnels *in reverse*. Two examples are considered: (1) a modification of the Ludwieg Tube and (2) the Isentropic Light Piston Tunnel. The sizes of tunnels required to meet the European and American specifications for a high-Reynolds-number tunnel with a 10-second running time are given together with proposals for a more modest national or university facility with a 1-second test time.

*Cranfield Institute of Technology, Cranfield, Beds MK43 0AL, England
**National Aeronautical Laboratory, Kodihalli, P.O. Bag 1779, Bangalore 560017, India

75. *Haut, R. C.: **Evaluation of Hydrogen as a Cryogenic Wind Tunnel Test Gas.** Ph.D. Thesis, Old Dominion University, 1977, 160 pp., 6 refs. Available Univ. Microfilms, Order #77-17259.

N78-12103

A theoretical analysis of the properties of hydrogen was made to determine the suitability of hydrogen as a cryogenic wind-tunnel test gas. By using cryogenic hydrogen, a significant increase in the test Reynolds number is achieved without increasing the aerodynamic loads. Nondimensional ratios used to describe various flow situations in hydrogen show cryogenic hydrogen is unacceptable as a wind-tunnel test gas in compressible flow. However, in incompressible flow, cryogenic hydrogen is acceptable. Hydrogen properties and fan drive-power requirements related to a hydrogen wind tunnel were also studied.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.

76. *Baals, D. D., Ed.: **High Reynolds Number Research.** NASA CP-2009, 1977. A workshop, sponsored in part by George Washington Univ., held at Langley Research Center, Hampton, Va., October 27-28, 1976, 192 pp.

N77-27139#

Note: For selected papers presented at this workshop see citation nos. [47] through [50] in this bibliography.

This report discusses the fundamental aerodynamic questions for which high-Reynolds-number experimental capability is required. It also reviews the operational characteristics and design features of the U.S. National Transonic Facility (NTF).

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

77. *Goodyer, M. J.: **The 0.1 m Subsonic Cryogenic Tunnel at the University of Southampton.** NASA CR-145305, January 1978, 5 refs., 43 pp.

N78-18086#

The design and performance of a low-speed, 1-atm cryogenic wind tunnel is described. The tunnel is fan driven and operates over the temperature range 305 K to 77 K at Mach numbers up to 0.28. It is cooled by the injection and evaporation of liquid nitrogen in the circuit and the usual test gas is nitrogen. The tunnel has a square test section 0.1 m across. It was built to allow low-cost development of testing techniques; allow the development of instrumentation for use in cryogenic tunnels; and to exploit, in general instrumentation work, the unusually wide range of unit Reynolds number available in such tunnels. The tunnel was first used in the development of surface flow-visualization techniques for use at cryogenic temperatures.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England
NASA Grant NSG-7172

78. *Ray, E. J.: **Langley's Two-Dimensional Research Facilities: Capabilities and Plans.** In: "Advanced Technology Airfoil Research," Vol. 1, Part I, (N79-20030), March 7-9, 1978, pp. 399-414, 10 refs.

N79-20055#

The current capabilities and the plans for NASA Langley's two-dimensional research facilities are described. The characteristics of the NASA Langley facilities are discussed in terms of Reynolds number, Mach number, and angle-of-attack capabilities. Comments are made with regard to the approaches which have been used to alleviate typical problem areas such as wall-boundary effects. Because of the need for increased Reynolds number capability at high subsonic speeds, a considerable portion of the paper deals with a description of the 20- by 60-cm two-dimensional test section of the 0.3-m Transonic Cryogenic Tunnel currently in the calibration and shakedown phase.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

79. *Ladson, C. L.: **A New Airfoil Research Capability.** In: "Advanced Technology Airfoil Research," Vol. 1, Part I, (N79-20030), March 7-9, 1978, pp. 425-432, 5 refs.

N79-20057#

The design and construction of a self-streamlining wall test section for the NASA Langley 0.3-m Transonic Cryogenic Tunnel was included in the fiscal year 1978 construction of facilities budget for NASA Langley Research Center. The design is based on the research being carried out by M. J. Goodyer at the University of Southampton, Southampton, England, and is supported by NASA Langley Research Center. This paper presents a brief description of the project. Included are some of the design considerations, anticipated operational envelope, and sketches showing the detail design concepts. Some details of the proposed operational mode, safety aspects, and preliminary schedule are also presented.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

80. *Nicks, O. W.; and *McKinney, L. W.: **Status and Operational Characteristics of the National Transonic Facility.** Presented at the AIAA 10th Aerodynamic Testing Conference, San Diego, Calif., April 19-21, 1978. Technical Papers, pp. 40-42.

AIAA paper 78-770 A78-32331#

This paper discusses the development and capabilities of the U.S. National Transonic Facility (NTF) which is planned for operation in 1981. The fan-driven, cryogenic-pressurized, closed-return tunnel will have operating parameters of 0.1-1.2 Mach, 1-9 bars pressure, 78-340 K, 150 dB sound pressure, and ±0.001 rms turbulence intensity. These operating conditions have been selected on the basis of several current and future aircraft and space transportation systems. The NTF will provide full-scale testing conditions for calculating subsonic drag, airloads, and stability and control information. Data for pre-test conditions, on-line information, and post-test analysis will be computer processed.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

81. *Inger, G. R.: **On The Simulation of Transonic Shock-Turbulent Boundary Layer Interactions in Cryogenic or Heavy Gas Wind Tunnels.** VPI-Aero-080, April 1978, 26 pp. Presented at the AIAA 10th Aerodynamic Testing Conference, San Diego, Calif., April 19-21, 1978. Technical Papers, pp. 285-292, 18 refs. Also, Journal of Aircraft, vol. 16, no. 4, April 1979, pp. 284-287, 11 refs.

AIAA Paper 78-808 N78-24501#
A78-32362#

Note: For further analysis by Adcock, see citation no. [186] in this bibliography.

The role of the basic similitude parameters governing transonic normal shock-turbulent boundary-layer-interaction effects in cryogenic wind-tunnel tests is studied theoretically for the non-separating case. Besides Mach and Reynolds number, these parameters are the wall to total temperatures ratio, specific heat ratio γ, viscosity-temperature exponent, and Prandtl number. The results show that lack of temperature ratio simulation has a significantly adverse effect on interactive skin friction and, hence, separation onset compared to the adiabatic free flight case; higher γ's than air also may cause some effect.

*Virginia Polytechnic Institute and State University, Blacksburg, VA 24060 U.S.A.

82. *Hall, R. M.: **Condensation and Its Growth Down the Test-Section of the Langley 0.3-M Transonic Cryogenic Tunnel.** Presented at the AIAA 10th Aerodynamic Testing Conference, San Diego, Calif., April 19-21, 1978. Technical Papers, pp. 301-304, 6 refs.

AIAA Paper 78-811 A78-32365#

Four total-pressure probes were used to measure the growth of condensation down the test section of the NASA Langley 0.3-m Transonic Cryogenic Tunnel. The condensation data were used to verify a mathematical model which assumes condensation results from heterogeneous nucleation on pre-existing seed particles. The onset of effects occurs throughout the test section at the same total temperature, but the magnitude of the effects increases with increasing length down the test section. Condensation is important because it determines the minimum operating temperature of transonic cryogenic wind tunnels.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

83. *Prieur, J.; and *Dor, J.-B.: **Estimation des pertes Termiques et Calculs des Caracteristiques de l'Ecoulement dans une Soufflerie a Rafales Cryogeniques. (Estimating heat losses and calculating flow characteristics in an intermittent cryogenic wind tunnel)**, DCAF F070143, June 1978, 44 pp., 3 refs., in French. NASA TT-20207, (X88-10111), March 1988, is an English translation.

N84-75683

This paper discusses the heat flux transmission phenomena of the various elements of the aerodynamic system of the T'2 wind tunnel at ONERA/CERT. It is possible to estimate the thermal losses and make a comparison with the theoretical thermal balance. The internal insulation is found to be quite effective. Equations are developed which describe the flow in this cryogenic wind tunnel.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

84. *Hartzuiker, J. P.; and *North, R. J.: **The European Transonic Wind-Tunnel Project.** Presented at the 7th Int. Cryogenic Engineering Conference. In: Proceedings, ICEC 7, London, England, July 4-7, 1978, pp. 322-330, 8 refs.

A79-31021

In 1978, four European nations agreed to cooperate in developing a large transonic high-Reynolds-number wind tunnel which would use cold nitrogen gas as the test medium. A test-section size of 1.95 × 1.65 m is envisaged. A continuous fan drive would provide runs with 10 periods of data acquisition, each lasting 10 minutes; a typical day could yield four runs. Cryogenic engineering problems related to the construction of the wind tunnel are also considered.

*Technical Group ETW, c/o National Aerospace Laboratory, 1006 BM Amsterdam, The Netherlands

85. *Michel, R.; and *Faulmann, D.: **Preliminary Tests in a Cryogenic Wind Tunnel Driven by Induction.** ONERA-TP-1978-48E, July 1978, 9 pp. Translation into English of La Recherche Aerospatiale, Bulletin Bimestriel (Paris) no. 1978-4, July-August 1978, pp. 205-207.

N80-12019#

A 1/4-scale cryogenic operation pilot wind-tunnel test for higher Reynolds number was made to verify a liquid nitrogen injection fast cooling process. The cryogenic operation was combined with an induction-driven operation in the hope that the short flow duration will give rise to a decrease in the wall and model surface temperature only, avoiding some technological problems. Operation temperatures down to 100 K were obtained. Thin layers of wall insulation are shown to be efficient in reducing nitrogen consumption. It is concluded that the simplicity of implementation makes the process promising for adapting existing wind tunnels to cryogenic operation.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

86. *Michel, R.; and *Faulmann, D.: **Preliminary Tests in a Cryogenic Transonic Wind Tunnel Driven by Induction.** La Recherche Aerospatiale, vol. 185, no. 4, July-August 1978, pp. 205-207, in French.

A79-15300#

Note: For an English translation, see the previous citation in this bibliography.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

87. *Hartzuiker, J. P.; and *North, R. J.: **The European Transonic Windtunnel (ETW) for High Reynolds-Number Testing.** Presented at the 11th Congress of ICAS, Lisbon, Spain, September 11-16, 1978, Rep. no. TG-ETW/D2, September 1978, pp. 94-103, 14 refs.

A81-14387#

A joint project of four nations (France, Germany (FRG), The Netherlands, and England) to define, and later to construct, a new European high-Reynolds-number transonic wind tunnel using cold nitrogen gas as the test medium is described. The concept of wind-tunnel testing at cryogenic temperatures is discussed and a brief description of the proposed tunnel, as it is envisaged at present, is given.

*Technical Group ETW, c/o National Aerospace Laboratory, 1006 BM Amsterdam The Netherlands

88. *Kell, D. M.: **A Surface Flow Visualization Technique for Use in Cryogenic Wind Tunnels.** Aeronautical Journal, vol. 82, November 1978, pp. 484-487, 4 refs.

A79-20795

A method of surface flow-visualization for use in cryogenic wind tunnels is described which requires injection of a cryogenic liquid onto the model while the tunnel is running. This necessitates the use of a substance that remains liquid over a large range of cryogenic wind-tunnel operating temperatures. It is found that propane (C_3H_8) is a suitable substance. Experiments are made in a subsonic cryogenic wind tunnel to assess the practical use of liquid propane flow visualization. The propane is stored in a chamber cooled by liquid nitrogen and when required is pumped through pipes to a gallery inside the model and then out onto the surface through small holes. A suspension of pigment particles is used to color the liquid. Propane is supplied to the cooled chamber in gaseous form from a standard liquefied gas cylinder. The sequence of events is illustrated on a propane temperature-entropy diagram. The use of liquefied propane for flow visualization in a cryogenic wind tunnel operating at pressures up to 40 atm appears to be feasible. Illustrative examples are provided.

*British Aerospace, Brooklands Rd., Weybridge, Surrey KT1 0SJ, England
NASA Grant NSG-7172

89. *Clausing, A. M.; *Clark, G. L., Jr.; and *Mueller, M. H.: **The Cryogenic Heat Transfer Tunnel - A New Tool for Convective Research.** Presented at the Winter Annual Meeting, ASME, San Francisco, Calif., December 10-15, 1978, pp. 73-78, 2 refs.

A79-24316#

A novel heat-transfer technique, the use of cryogenic temperatures for convective modeling, is used in this study to obtain simultaneously large Grashof and Reynolds numbers on a vertical cylinder. The research is motivated by the need to predict combined convective losses from large, high-temperature objects such as solar "power tower" receivers where the magnitudes of both the Grashof and Reynolds numbers are large. The cryogenic heat-transfer tunnel provides an economical method of obtaining these large Grashof and Reynolds numbers with an appropriate and nearly constant Prandtl number; thus, it is an excellent tool for study of convective heat transfer. Low-temperature modeling, a cryogenic testing facility, and a transient measurement technique are discussed.

*University of Illinois at Urbana-Champaign, Urbana, IL 61801 U.S.A.
Research support by Dept. of Energy
Research Grant no. 87-9180

90. *Hottner, T.: **Anwendung der Tieftemperaturtechnik im stromungstechen Versuchswesen. (The Application of Cryogenics in Experimental Aerodynamics.)** Ingenieur-Archiv, vol. 47, no. 4, 1978, pp. 241-256, 13 refs., in German. For translation, see NASA TM-75385.

A78-48982, in German
X79-10099, in English

The use of cryogenics in wind-tunnel design offers an increase in Reynolds number at reduced drive power for the wind-tunnel compressor compared to a wind tunnel driven at normal temperatures. The price, however, is an additional cryogenic power. The report is concerned with the energetic aspect of cryotechnics in wind-tunnel technique. With restriction only on cryogenic power due to tunnel process-heat, the continuously running tunnel with closed circuit and the blowdown storage tunnel are studied. Finally, the possibility of reducing cryogenic power using heavy gases as the test medium is discussed.

*Universität Stuttgart, Pfaffenwaldring 27, D-7000 Stuttgart 80, FRG

91. *Liepmann, H. W.; and *Coles, D.: **Proceedings: Workshop on High-Reynolds-Number Flow.** Final Technical Report, NSF Grant EGN 7823543, August 1979. Held January 11-12, 1979, 36 pp.

NASA Langley Technical Library Number CN-159,406

On January 11-12, 1979, a workshop was held at the California Institute of Technology to discuss a proposal by H. W. Liepmann to build a liquid-helium tunnel capable of operating at supersonic speeds at cryogenic temperatures. The tunnel test section would be about 3 cm on a side and the operating time would be about 10 seconds in a blowdown mode. Part of the discussion centered around the opportunity provided by such a facility to study the physics and fluid mechanics of liquid helium (a) near the λ transition and (b) near the critical point. Another part of the discussion dealt with instrumentation problems. The remaining discussion centered around costs and benefits of fluid-mechanics research at the very high Reynolds numbers which would automatically be accessible in such a cryogenic facility.

*California Institute of Technology, Pasadena, CA 91125 U.S.A.

92. *Hall, R. M.; and **Kramer, S. A.: **A Review of "At Rest" Droplet Growth Equations for Condensing Nitrogen in Transonic Cryogenic Wind Tunnels.** NASA TM-78821, January 1979, 36 pp., 18 refs.

N79-15001#

Droplet growth equations are reviewed in the free-molecular, transition, and continuum-flow regimes with the assumption that the droplets are "at rest" with respect to the vapor. As comparison calculations show, it is important to use a growth equation designed for the flow regime of interest. Otherwise, a serious overprediction of droplet growth may result. The growth equation by Gyarmathy appears to work throughout the flow regimes and involves no iteration. His expression also avoids the uncertainty associated with selecting a mass accommodation coefficient and, consequently, involves less uncertainty in specifying adjustable parameters than many of the other growth equations.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
**University of Virginia, Charlottesville, VA 22904 U.S.A.

93. *Bursik, J. W.; and **Hall, R. M.: **Metastable Sound Speed in Gas-Liquid Mixtures.** NASA TM-78810, March 1979, 54 pp., 13 refs.

N79-20339#

A new method of calculating speed of sound for two-phase flow is presented. The new equation assumes no phase change during the propagation of an acoustic disturbance and assumes that only the total entropy of the mixture remains constant during the process. The new equation predicts single-phase values for the speed of sound in the limit of all gas or all liquid and agrees with available two-phase, air-water sound speed data. Other expressions used in the two-phase flow literature for calculating two-phase, metastable sound speed are reviewed and discussed. Comparisons are made between the new expression and several of the previous expressions–most notably a triply isentropic equation as used, among others, by Karplus and by Wallis. Appropriate differences are pointed out and a thermodynamic criterion is derived which must be satisfied for the triply isentropic expression to be thermodynamically consistent. This criterion is not satisfied for the cases examined, which included two-phase nitrogen, air-water, two-phase parahydrogen, and steam-water. Consequently, the new equation is superior to the other equations reviewed.

*Rensselaer Polytechnic Institute, Troy, NY 12181 U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

94. *Wagner, B.; and *Schmidt, W.: **Theoretical Studies on the Shock Wave-Boundary Layer Interaction in Cryogenic Nitrogen.** Rept. no. ESA-TT-498, March 1979, pp. 419-436, 15 refs.

N79-31569#

Note: This is an English translation of the 1977 German report previously announced as N79-12402; see citation no. [61] in this bibliography.

The basic effects of low temperatures close to liquefaction in cryogenic wind tunnels were studied theoretically for viscous-compressible flow on the basis of shock-wave laminar boundary-layer interaction. The full Navier-Stokes equations, in combination with the equations of state for a real gas and the material properties for low temperatures, were solved by a finite volume method and MacCormack's time-splitting technique. Results show relatively small deviations compared with the ideal-gas case. The differences in the pressure distribution are caused mainly by real-gas effects in the inviscid external flow field. The changes in the skin-friction coefficients depend mainly on the different viscosity characteristics and on the real-gas effects in the temperature distribution.

*Dornier GmbH–Friedrichshafen 1, Postfach 1420, D-7990 Friedrichshafen 1, FRG

95. *Goodyer, M. J.: **The Evolution of the Cryogenic Wind Tunnel.** Paper no. 1, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 5 pp. In: Proceedings, A80-24078, 1979, pp. 1.1–1.5, 5 refs.

TL 567.W5157, 1979, pp. 1.1-1.5 A80-24078#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

The main aim of this paper is to trace the key events in the emergence of the cryogenic wind tunnel, events which led, therefore to this symposium, to learn of its present state of development and to gain insight into the future pattern of evolution. A secondary aim is to attempt to influence evolution by drawing attention to areas of endeavor which are not receiving the degree of research effort which may be justified.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

96. *Bazin, M.; and *Dubois, M.: **Balance and Sting Design for Cryogenic Wind Tunnels.** Paper no. 2, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, ONERA-TP-1979-40, April 3-5, 1979, 8 pp., 15 refs.

A79-39089#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

The orientations and thoughts leading to the concept of balances and stings usable in the future European Transonic Windtunnel (ETW) are presented in this paper. They constitute the starting point of a national research program integrated within the European program. The domain considered is that of ETW cryogenic runs of about 10 minutes, from 120 to 300 K; stagnation pressure of 1 to 4.4 bar; and Mach number of 0.2 to 1.35.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

97. *Krogmann, P.; and *Lorenz-Meyer, W.: **Design and Testing of an Unheated Strain Gauge Balance Element for Cryogenic Temperatures.** Paper no. 3, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 9 pp., 4 refs.

A80-24079#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

To develop unheated strain-gauge balances for use in cryogenic wind tunnels at low temperatures, experiments were undertaken at DFVLR Göttingen on single-component elements made of different steels and equipped with different types of strain gauges. Disappointingly, bad results were obtained when unsuitable strain gauges were used on two identical elements of austenitic stainless steel. Subsequent experiments with another type of strain gauge on the same elements showed better but still poor results, which obviously have to be attributed to temperature-dependent variations of the material properties. Finally, another element was manufactured of different steel. This element, in connection with suitable strain gauges, so far has given the most promising results.

*DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

98. *Liousse, F.; *Calvet, P.; and *Giovannini, A.: **Experimental Study of Thermoresistive Sensors Under Cryogenic Conditions.** Paper no. 4, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 9 pp., 4 refs.

A80-24080#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

Thermoresistive sensors (commercially available "hot" wire or film-type probes) are tested under steady and unsteady cryogenic flows to determine their ability to operate in cryogenic wind tunnels for instantaneous temperature and velocity measurements. Some specific devices have been designed. They consist of a small calibration tunnel performing controlled velocity variations and an electronic thermometer with a built-in circuit which permits *in situ* measurement of response time of the sensors.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

99. *Hartzuiker, J. P.; and *North, R. J.: **A Progress Report on the European Transonic Windtunnel Project.** Paper no. 5, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 5 pp., 5 refs.

A80-24082#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

This paper was written about a year after the start of the Preliminary Design Phase of ETW. The organizational structure was established, the preliminary design of the pilot tunnel was finished, and the preliminary design of ETW was well under way. A substantial cryogenic technology programme had been initiated. Strong support was being given from many quarters to the work of the Technical Group. A further Memorandum of Understanding for the next Phase or Phases was under consideration and preparations were being made for a decision on the site. This all represented real progress toward the realization of the European Transonic Windtunnel in the mid-1980s.

*Technical Group ETW, c/o National Aerospace Laboratory, 1006 BM Amsterdam The Netherlands

100. *Nelander, C.: **A Self-Contained Cryogenic Air Supply System for a Transonic Blow-Down Tunnel.** Paper no. 6, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 5 pp.

A80-24083#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

A high-pressure air supply system can be used not only to feed a wind tunnel but also to reduce the total enthalpy of the gas. This can be done by various methods and to such an extent that cryogenic stagnation temperatures are achieved. This paper deals with some different methods which could be used to incorporate the cold-generating process into the wind-tunnel run sequence. It is shown that with a huge low-pressure air storage already on hand (as the case is at FFA), the most attractive scheme should be to store the cold outlet air from the tunnel and to use this low-enthalpy gas for cooling off the compressed air when the high-pressure storage is recharged.

*Aktiebolaget Rollab, Jarvstigen 5, Box 7073, S-171 07 Solna, Sweden

101. *Ashcroft, D. H.; and *Emslie, K.: **A Cryogenic Transonic Blowdown Wind Tunnel Project.** Paper no. 7, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 8 pp.

A80-24084#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

Combat aircraft operate within the range of serious scale effects; hence, wind-tunnel tests require full simulation of Reynolds number if seriously misleading results are to be avoided. Although there are many claims on the capital within the aircraft industry, the provision of a high-Reynolds-number facility will produce cost-effective returns. Means to achieve this are considered relative to capital and running costs. Long experience with a blowdown to atmosphere wind tunnel has been taken as the basis for a cryogenic version. Injection and evaporation of liquid nitrogen downstream of the airflow control valve will cool the test gas to flow across a previously cooled model. The test gas will be discarded, despite the high cost per run, because the alternatives which use natural cooling processes, recirculation, or energy saving would be much more costly to build. The major features of the project and potential performance are described. Comments are made on the key areas requiring experimental development work and on the program that will be undertaken to produce a successful facility.

*British Aerospace, Wharton Aerodrome, Preston, Lancs PR4 1AX, Lancashire, England

102. *Hutt, G. R.; and *East, R. A.: **Preliminary Studies of a Free Piston Expander for an Intermittent Cryogenic Wind Tunnel.** Paper no. 8, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 5 pp., 3 refs.

N80-24085#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

This paper presents preliminary experimental results of measurements of the tunnel stagnation temperatures achieved in a small-scale, free-piston device and of measurements to determine the effect of heat transfer from the tube on the uniformity of the conditions achieved. Results are presented of experiments using a small-scale, free-piston expansion-drive system proposed by Stollery and Murthy for an intermittent cryogenic wind tunnel. The feasibility of the proposed operating principle is demonstrated and measurements of pressure and temperature during the expansion, and run periods are compared with the predictions of a simple theoretical model.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

103. *Haldeman, C. W.; **Kraemer, R. A.; and *Way, P.: **Developments at M.I.T. Related to Magnetic Model Suspension and Balance Systems for Large Scale Facilities.** Paper no. 9, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 15 pp., 17 refs.

A80-24087#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

Magnetic model suspension and balance systems for wind-tunnel use have been designed, tested, and used at M.I.T.'s Aerophysics Laboratory for over 18 years. Despite this experience, which demonstrates the utility and durability of the magnetic model suspension and balance systems, no large-scale system has yet been built anywhere in the world. This appears to be due principally to the large capital cost of such a system. This paper presents several attributes of magnetic balance systems which make them attractive for use in large-scale cryogenic wind tunnels. This paper also describes recent developments in model roll control and superconducting coil construction which enhance system versatility and reduce the electrical power requirements.

*Massachusetts Institute of Technology, Aerophysics Laboratory, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.
**Arizona State University, Tempe, AZ 85281 U.S.A.

104. *Britcher, C. P.; and *Goodyer, M. J.: **The Southampton University Magnetic Suspension/Cryogenic Wind Tunnel Facility.** Paper no. 10, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 9 pp., 7 refs.

A80-24088#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

Scaling laws relating design parameters of magnetic suspension and balance systems to wind-tunnel test conditions are identified. Reduction of test temperature is found to be the most attractive and powerful technique of reducing the cost of a magnetic suspension system for specific test Reynolds number and Mach number requirements. This paper gives details of the adaption of a small, low-speed, fan-driven cryogenic wind tunnel for use with a magnetic suspension and balance system. Aerodynamic data have been acquired from a model suspended in the new facility over a wide range of tunnel conditions. Temperature is shown to have a small effect on the magnetization of the model magnetic cores. Studies of the effect have begun.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

105. *Kilgore, R. A.; *Igoe, W. B.; *Adcock, J. B.; *Hall, R. M.; and *Johnson, C. B.: **Full-Scale Aircraft Simulation With Cryogenic Tunnels and Status of the National Transonic Facility.** Paper no. 11, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, NASA TM-80085, (N79-26064#), April 3-5, 1979, 18 pp., 29 refs.

A80-24090#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

We have made theoretical studies to determine the effect of thermal and caloric imperfections in cryogenic nitrogen on boundary layers. To simulate nonadiabatic laminar or turbulent boundary layers in a cryogenic nitrogen wind tunnel, the flight-enthalpy ratio, rather than the temperature ratio, should be reproduced. The absence of significant real-gas effects on both viscous and inviscid flows makes it unlikely there will be large real-gas effects on the cryogenic tunnel simulation of shock boundary-layer interactions or other complex flow conditions encountered in flight. Experimental and theoretical studies on condensation effects have been made to determine the minimum usable stagnation temperature. Considerable evidence indicates that under most circumstances free-stream Mach number rather than maximum local Mach number determines the relevant saturation boundary and thereby determines the onset of condensation effects. Progress is well under way on a major use of the cryogenic wind-tunnel concept with the construction of the U.S. National Transonic Facility at the NASA Langley Research Center. This new tunnel is scheduled to become operational by 1982. It provides an order of magnitude increase in Reynolds-number capability over existing U.S. tunnels. Because of the ability to vary pressure, Mach number, and temperature independently, it will also be able to separate aeroelastic, compressibility, and viscous effects on the aerodynamic parameters being measured.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

106. *Edmundson, I. C.: **The Generation of Cryogenic Temperatures by High Pressure Expansion.** Paper no. 12, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 3 pp., 8 refs.

A80-24091#

Note: For the complete compilation of papers see citation no. [174] in this bibliography.

In designing an intermittent cryogenic tunnel, it would seem logical to create the conditions intermittently. Stollery proposed this could be done using the expansion of a high-pressure gas. A proposed scheme is explained. The calculation assumed an adiabatic, isentropic expansion. This paper reviews the available experimental evidence to examine this assumption. From the evidence presented, the deviations from an adiabatic, isentropic expansion has important implications for the design of this tunnel. Previous experimental work on the expansion of gases has shown that these deviations are significant. Experimental work is being carried out to assess a more realistic configuration.

*Cranfield Institute of Technology, Cranfield, Beds MK43 0AL, England

107. *Blanchard, A.; and *Faulmann, D.: **Progress Report on a Cryogenic Pilot Transonic Wind Tunnel Driven by Induction.** Paper no. 13, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 13 pp., 3 refs.

A80-24092#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

A promising solution to increase the Reynolds number without producing too many technological problems seems to be provided by a short cryogenic operating run, in which the cooling is ensured by a quick injection of liquid nitrogen in the return leg circuit. A thin layer of internal thermal insulation allows a reduction of thermal losses and nitrogen consumption. This solution has been chosen for transforming existing wind tunnels and, in particular, for the adaptation of T2 for cryogenic operation. In our present installation, we are studying and resolving satisfactorily many problems connected with general cryogenic wind-tunnel operation. Many problems of low-temperature operation must be solved through such fundamental studies before the error-free realization of large tunnels can be made.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

108. *Luneau, J.; *Rochas, N.; and *Kirrmann, C.: **Preliminary Study of the Injection Process of LN_2 in a Cryogenic Wind-Tunnel.** Paper no. 14, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 10 pp., 5 refs.

A80-24093#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

The *Ecole Nationale Superieure de l'Aeronautique et de l'Espace* (ENSAE) in collaboration with the *Centre d'Essais Aeronautique de Toulouse* (CEAT) has been studying a transonic cryogenic wind tunnel. This wind tunnel, now being built, is to be operational by the end of 1980. It has been conceived to study airfoils in transonic flow. To be sure the liquid nitrogen has disappeared inside the test section, a study was made to determine the characteristics and the location of injectors able to maintain a single phase, steady uniform flow in the test section. The theoretical study is being oriented toward modeling of breakup and coalescence phenomena. A small wind tunnel with a 60- × 120-mm test section is now being built and will be used to study the influence of different parameters such as injection velocity, gas flow velocity, and gas temperature. The final aim consists in validating a theoretical model of the two-phase flow, which would allow us to determine the optimal characteristics and position of the LN_2 injectors to be set in the ENSAE wind tunnel and other cryogenic wind tunnels of the future.

*ENSAE/CEAT, 10, av. Edouard-Belin, B.P. 4032, F-31055 Toulouse Cedex, France

109. *Koppenwallner, G.; and *Dankert, C.: **The Homogeneous Nitrogen Condensation in Expansion Flows With ETW-Relevant Stagnation Conditions.** Paper no. 15, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 10 pp., 12 refs.

A80-24095

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

The condensation in free-jet expansions with stagnation conditions typical for transonic cryo-tunnels was studied. The results show the delay for condensation onset and the gas dynamic behavior within the condensation regime. Although the experiments were made in small-scale nozzles, they nevertheless can be used to predict condensation delay in model flow fields.

*DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

110. *Younglove, B. A.: **Thermodynamic Properties of Nitrogen Gas From Sound Velocity Measurements.** Paper no. 16, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 6 pp., 10 refs.

A80-24096#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

We have calculated the thermodynamic properties of nitrogen gas from 80 to 350 K and at pressures to 10 bar from sound speed measurements and existing P-V-T data using multiproperty fitting techniques. These new data are intended to improve existing predictive capability of the equation of state in the low-density region needed for use with the U.S. National Transonic Facility (NTF) now being built at the NASA Langley Research Center.

*National Bureau of Standards, Boulder Laboratories, Boulder, CO 80302 U.S.A.

111. *Albone, C. M.: **An Investigation Into the Real Gas Effects of Cryogenic Nitrogen in Inviscid Homentropic Flow.** Paper no. 17, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 4 pp., 3 refs.

A80-24094#

Note: For another version of this report, see citation no. [133] in this bibliography. For the complete compilation of papers, see citation no. [174] in this bibliography.

As a contribution to the investigation of the suitability of using cryogenic nitrogen as the test gas in a high-Reynolds-number transonic wind tunnel, a study is made of the real-gas effects of nitrogen at low temperatures. The study, limited to inviscid, homentropic flow of a nonconducting gas, takes the form of an independent confirmation of results by Kilgore et al. The new contribution in this paper is that the use of a simplified equation of state enables an expression for enthalpy (and hence the terms in Bernoulli's equation) to be derived by analytic integration.

*Royal Aircraft Establishment, Farnborough, Hants GU14 6TD, England

112. *Inger, G. R.: **Transonic Shock-Boundary Layer Interactions in Cryogenic Wind Tunnels.** Paper no. 18, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 9 pp., 24 refs.

A80-24097#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

Since the transonic aerodynamics of missiles and aircraft can be significantly influenced by shock-wave, boundary-layer-interaction effects, these effects should be adequately simulated in cryogenic high-Reynolds-number wind-tunnel experiments. In addition to flight Mach and Reynolds numbers which are simulated by design, there are four other interaction similitude parameters which may not be duplicated owing to the very low-temperature/high-pressure working fluid involved: wall to total temperature ratio T_w/T_o specific heat ratio γ, viscosity temperature exponent ω, and Prandtl number Pr. The first is deemed especially important since in some proposed short-duration cryogenic transonic wind tunnels the model is at much higher temperature than T_t during the test. Moreover, the γ of cryogenic nitrogen can be larger (1.5-1.8) than air and thus influence the interaction; lower γ's are also of interest in heavy-gas (for example, Freon 12) facilities. This paper describes the use of an approximate nonasymptotic theory of weak normal shock nonseparating turbulent boundary-layer interaction to the prediction of these heat-transfer and real-gas effects.

Note: See citation no. [186] in this bibliography for further analysis by Adcock.

*Virginia Polytechnic Institute and State University, Blacksburg, VA 24060 U.S.A.

113. *Smith, D. A.: **Development of a Test Procedure for Acoustically Dissipative Silencer Materials Used in Cryogenic Applications.** Paper no. 19, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 9 pp., 4 refs.

A80-24098#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

The purpose of the test procedure discussed is to guide selection of optimum mechanical properties of acoustically dissipative materials to be used in silencers for cryogenic applications. The items of primary concern are erosion of materials due to grazing flow, fatigue of materials due to grazing flow and intense sound-pressure levels, and thermal shock of materials due to cryogenic temperatures. The proposed test procedure quantifies the degradation of mechanical properties of acoustically dissipative materials intended for use in an intense acoustic field, with flow at cryogenic temperatures.

*General Acoustics Corp., 12248 Santa Monica Blvd., Los Angeles, CA 90025 U.S.A.

114. *North, R. J.: **The Cryogenic Technology Programme of the European Transonic Windtunnel Project.** Paper no. 20, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 8 pp., 1 ref.

A80-24099#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

The European Transonic Windtunnel (ETW) project is concerned with the design and feasibility of a proposed large new ETW operating on the cryogenic principle. There are a number of problems to be solved in the design, construction, and operation of such a tunnel. Among these problems are those of instrumentation, model design and construction, testing techniques, minimum operating temperature, and so on. If it appears there are basic difficulties in any of these areas, the acceptability of the proposed tunnel to prospective users might be in doubt. Accordingly, the Steering Committee of ETW has initiated a so-called cryogenic technology programme to examine these problems. A list of possible subjects of interest in a cryogenic technology programme is given. The present cryogenic technology programme is listed. A comparison of these lists shows a combination of exchanges of information, an atmosphere of goodwill, and positive measures by the national representatives on the Steering Committee and by representatives of the aircraft industries, has resulted in a program which covers a large part of the spectrum of interest.

*Technical Group ETW, c/o National Aerospace Laboratory, 1006 BM Amsterdam The Netherlands

115. *Haldeman, C. W.: **Suggested Modification of Fog Flow Visualization for Use in Cryogenic Wind Tunnels.** Paper no. 21, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 3 pp., 2 refs.

A80-24100#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

We have recently used a mixture of liquid nitrogen and steam-bearing air to produce flow visualization in a conventional subsonic wind tunnel. This note offers the suggestion that this technique might be modified to produce nitrogen "smoke" for flow visualization in cryogenic wind tunnels.

*Massachusetts Institute of Technology, Aerophysics Laboratory, 77 Massachusetts Avenue, Cambridge, MA 02139 U.S.A.

116. *Morel, J. P.; and **Mereau, P.: **Optimum Control of the European Transonic Windtunnel.** Paper no. 22, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 10 pp., 8 refs.

A80-24102#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

Analyses of European Transonic Windtunnel (ETW) operating costs have shown the large influence of liquid nitrogen consumption during transients. Optimization of control for ETW is desirable; it involves a theoretical and experimental programme during preliminary design so, by the time of ETW construction, theoretical models checked through experiments will help in the design of control architecture. Interfaces between control and other tasks will be examined thoroughly. A simplified model has shown the highly-coupled aspect of ETW flow dynamics. Optimum control of the tunnel parameters (Mach number, stagnation temperature, and stagnation pressure) by use of the predictive algorithm IDCOM looks feasible based on some simulation on the simplified model. Preliminary results of the identification of Mach number process in the NLR HST show that the validity of using the simplified model for control purposes looks promising in that field. More analyses are still required of test results obtained in the 1 × 1 m DFVLR and ONERA-CERT T'2 wind tunnels. A general model with less restrictive assumptions is being implemented on a computer. It must be checked with simplified model results as well as with the experimental tests. By the end of this preliminary design phase, it is expected that use of theoretical models, validated by basic experiments, will give a first definition of an ETW control architecture.

*Technical Group ETW, c/o National Aerospace Laboratory, 1006 BM Amsterdam The Netherlands
**Adersa-Gerbios, Velizy, France

117. *Balakrishna, S.; and **Thibodeaux, J. J.: **Modeling and Control of a LN_2-GN_2 Operated Closed Circuit Cryogenic Wind Tunnel.** Paper no. 23, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 11 pp., 9 refs.

A80-24103#

Note: For the complete compilation of papers see citation no. [174] in this bibliography.

Full-scale Reynolds-number flow capability at transonic speeds has been successfully realized in wind tunnels by cooling the test gas to cryogenic temperatures. Gaseous nitrogen (GN_2) is an ideal cryogenic test medium because of its negligible thermal and calorific imperfections on isentropic expansion, and since it can be cooled efficiently by injected liquid nitrogen (LN_2) which evaporates into the test gas. Despite increased gas density, cryogenic operation of a closed-circuit wind tunnel is associated with reduced fan power and no extra dynamic loads on the models. Further, a closed-circuit cryogenic tunnel allows independent control of the tunnel flow parameters. Precise control of these parameters is an involved control problem in view of the nonlinear and coupled nature of the tunnel responses. This paper aims at developing a simple lumped parameter multivariable control compatible mathematical model of a LN_2-GN_2 operated closed circuit cryogenic tunnel, and deriving closed loop control laws with specific reference to the 0.3-m Transonic Cryogenic Tunnel at the NASA Langley Research Center.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
NASA Grant NSG-1503

118. *Clausing, A. M.: **Experimental Studies of Forced, Natural and Combined Convective Heat Transfer at Cryogenic Temperatures.** Paper no. 24, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 8 pp., 3 refs.

A80-24104#

Note: For the complete compilation of papers see citation no. [174] in this bibliography.

A novel heat-transfer technique, the use of cryogenic temperatures for convective modeling, is used in this study to obtain significant increases in $\rho^2\beta/\mu^2$ and ρ/μ, to obtain simultaneously large Grashof and Reynolds numbers on a vertical cylinder. The research is motivated by the need to predict combined convective losses from large, high-temperature objects such as solar "power tower" receivers where the magnitudes of both the Grashof and Reynolds numbers are large. The cryogenic heat-transfer tunnel provides an economical method of obtaining these large Grashof and Reynolds numbers with an appropriate and near constant Prandtl number; thus it is an excellent tool for study of convective heat transfer. Low-temperature modeling, a cryogenic testing facility, and a transient measurement technique are discussed.

*University of Illinois at Urbana-Champaign, Urbana, IL 61801 U.S.A.

119. *Christophe, J.; and *Francois, G.: **Thermal Insulation of Pressurized Cryogenic Wind Tunnels.** Paper no. 25, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 5 pp., 5 refs.

A80-24105#

Note: For the complete compilation of papers see citation no. [174] in this bibliography.

The transformation of existing wind tunnels for cryogenic operation requires an internal insulation to protect the walls, which usually are made of carbon steel, and are brittle at low temperatures. In order not to alter the shape of the aerodynamic circuit, a thin insulation is used that is efficient for a limited time only. A comparison of solutions with thick internal or external insulators allowed the study of the wall temperature evolution and of the energies implied during transient or permanent operations for long duration runs of several minutes to several tens of minutes. This paper presents a few remarks on the insulation of a wind tunnel with a view to its use down to 120 K. This fan-driven wind tunnel, still under construction, will have a test section area of 0.15 × 0.35 m, a maximum stagnation pressure of 5 bars and a maximum velocity of Mach 1.0. Initially designed for operation at room temperature, it is now being modified for operation at cryogenic conditions. To this end, the main circuit is being built in stainless steel Z2CN 18-10 (the American 304 L). Provisions are planned for injection and exhausting nitrogen and for thermal insulation.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

120. *Green, J. E.; *Weeks, D. J.; and *Pugh, P. G.: **Heat Transfer to Model or Test Section as a Source of Spurious Aerodynamic Effects in Transonic Wind Tunnels.** Paper no. 26, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 8 pp., 1 ref.

A80-24106#

Note: For the complete compilation of papers see citation no. [174] in this bibliography.

For predictions of aerodynamic characteristics to be reliable, correct simulation of the thermal behavior at full scale is essential. The ratio of surface temperature to free-stream temperature may be expected to be just as important a parameter as Reynolds number in any flow in which boundary-layer behavior has a significant effect to the overall aerodynamics. The relative importance of Reynolds number and of heat transfer to the model is assessed in this paper on the basis of calculations of the flow over an aerofoil at subsonic and transonic speeds. The significance of heat transfer to the test-section walls is also assessed. Hence, allowable temperature limits are suggested for both the model and the tunnel walls. The source of the results quoted here is a paper written in 1973 at the behest of the AGARD LaWs Group but given only limited circulation at that time. Whilst the theoretical methods used, particularly for the inviscid parts of the aerofoil calculations, have now been superseded by appreciably improved methods, there is no reason to suppose that the use of these later methods would significantly alter our main conclusions.

*Royal Aircraft Establishment, Farnborough, Hants GU14 6TD, England

121. *Mignosi, A.; and *Archambaud, J.-P.: **Prediction of Thermal Losses and Transient Flows in a Cryogenic Wind Tunnel.** Paper no. 27, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 9 pp., 5 refs.

A80-24107#

Note: For the complete compilation of papers see citation no. [174] in this bibliography.

We have developed theoretical methods in parallel with the experimental studies in an induction-driven cryogenic pilot wind tunnel called T2. This wind tunnel is used to give experimental data related to cryogenic problems. Prediction methods have been established to compute thermal losses, wind-tunnel performance, and transient flows. These methods have been checked with experimental data and are used to predict and to optimize the wind-tunnel flow. The contemplated application of these methods is a cryogenisation of our induction-driven wind-tunnel T2 (test section 0.4 × 0.4 m) in which we could obtain great values of Reynolds number.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

122. *Ray, E. J.; *Ladson, C. L.; *Adcock, J. B.; *Lawing, P. L.; and *Hall, R. M.: **Review of Design and Operational Characteristics of the 0.3-Meter Transonic Cryogenic Tunnel.** Paper no. 28, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 33 pp., 17 refs. Also NASA TM-80123.

A80-24108#

Note: See also citation no. [136] in this bibliography. For the complete compilation of papers, see citation no. [174] in this bibliography.

The past 6 years of operation with the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) has shown there are no insurmountable problems associated with cryogenic testing with gaseous nitrogen at transonic speeds. The fundamentals of the concept have been validated both analytically and experimentally. We have used the 0.3-m TCT, with its unique Reynolds-number capability, for a wide variety of aerodynamic tests. Techniques regarding real-gas effects have been developed and cryogenic tunnel conditions can be set and maintained accurately. Cryogenic cooling by injecting liquid nitrogen directly into the tunnel circuit imposes no problems with temperature distribution or dynamic response characteristics. However, experience with the 0.3-m TCT has shown there is a significant learning process associated with cryogenic, high-Reynolds-number testing. Many of the questions have already been answered; however, areas such as tunnel control, run logic, economics, instrumentation, and model technology present many new and challenging problems.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

123. *Richards, B. E.; and *Wendt, J. F.: **Preliminary Design Study of a Regeneratively-Cooled Transonic Cryogenic Tunnel.** Paper no. 29, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 3 pp., 3 refs.

A80-24109#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

The cost of liquid nitrogen dominates the operating expenses of a cryogenic tunnel, particularly in the high-speed range. To reduce this cost, a number of short-duration designs have been studied; many of them will be discussed at this symposium. One idea which does not seem to have received serious attention is the regeneratively-cooled concept. The purpose of this short paper is to present the concept for constructive criticism.

*von Karman Institute for Fluid Dynamics (VKI), 72, chaussée de Waterloo, B-1640 Rhode St. Genèse, Belgium

124. *Lambourne, N. C.: **Synopsis of Similarity Requirements for Aeroelastic Models in Cryogenic Wind Tunnels.** Paper no. 30, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 4 pp., 4 refs.

A80-24110#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

A consideration of the requirements for aeroelastic similarity shows the low working temperature of a cryogenic tunnel and an ability to vary temperature both have advantages in regard to the choice of suitable stiffness and density scales for an aeroelastic model. The advantages are incidental to the main purpose of a cryogenic tunnel, which is to achieve high Reynolds numbers.

*Royal Aircraft Establishment, Bedford, Beds MK41 6AE, England

125. *Gravelle, A.: **Aeroelastic Models for Cryogenic Wind Tunnels.** Paper no. 31, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979. ONERA TP-1979-39, 1979, 5 pp., 3 refs.

A79-39088#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

This paper examines application of Mach and Froude similarity rules to cryogenic wind-tunnel testing of aeroelastic models. It shows that when stagnation temperatures are low and can be varied over a wide range, it is possible to obtain reasonable values for static loads and Reynolds numbers with flutter models. The scaling of models of the Airbus A300B and the F1 fighter for testing in an S2-MA wind tunnel is discussed and compared with possible scalings of similar models for testing in a cryogenic wind tunnel.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

126. *Ferris, A. T.: **Cryogenic Wind Tunnel Force Instrumentation.** Paper no. 32, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 8 pp., 1 ref. Also NASA TM-81845.

A80-24081#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

A cryogenic wind tunnel imposes rather severe requirements on the measurement of aerodynamic forces and moments. Although pushing the state of the art, initial studies indicate we can build one-piece, high-capacity strain-gage balances to satisfy cryogenic requirements. This paper outlines the work accomplished at NASA Langley while studying the effects of the cryogenic environment on one-piece multicomponent strain-gage balances, with particular emphasis on cryogenic balances for use in the U.S. National Transonic Facility (NTF), a 2.5-m cryogenic wind tunnel being built at NASA Langley. We have designed one-piece multicomponent strain-gage balances to meet the requirements imposed by the cryogenic environment. These balances are a result of studies in the areas of design, balance materials, strain gages (including application techniques), and cryogenic calibration. The laboratory results indicate these balances will yield reliable, repeatable, and predictable data from 340 to 77 K under steady-state conditions. Work is continuing in a number of areas to reduce the effect of the cryogenic environment even further and to study the problems associated with thermal control that may be needed to eliminate thermal gradients.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

127. *Hill, E. G.: **The Proposed Boeing Supersonic Wind Tunnel High Reynolds Number Insert.** Paper no. 33, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 4 pp., 2 refs.

A80-24089#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

Modification of the infrequently used Boeing Supersonic Wind Tunnel (BSWT) to provide high-Reynolds-number testing capabilities has been under study since 1974. Operating the modified 4-foot tunnel at cryogenic temperatures produces full-scale Reynolds number with approximately 0.02-scale models. Plans are to continue a low-budget circuit development effort and to monitor progress in cryogenic wind-tunnel testing technology. Noncryogenic circuit development studies are scheduled for completion by the end of 1979. Subsequently, cryogenic circuit development studies in the 0.10-scale BSWT/BHRT pilot facility will continue during 1980. Limited studies are continuing to define the modifications required to convert the BSWT into a high-Reynolds-number tunnel, BHRT. Many of the noncryogenic modifications have been defined. Studies concerning cryogenic operations will begin late in 1979.

*Boeing Co., P. O. Box 3707, Seattle, WA 98124 U.S.A.

128. *Cadwell, J. D.: **Design, Fabrication, and Instrumentation Preparation of a Verification Model for the Douglas Aircraft Four Foot Cryogenic Wind Tunnel (4-CWT).** Paper no. 34, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 10 pp., 3 refs.

A80-24111#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

The advent of the cryogenic work at the NASA Langley Research Center presented the technique that would allow the McDonnell Douglas Corporation to obtain a high-Reynolds-number transonic wind tunnel with reasonable dynamic pressures for a moderate capital expenditure. Although NASA has a continuous-flow cryogenic pilot tunnel in operation, the blowdown concept had not been checked experimentally. Before approval of the capital expenditure, an in-house study was accomplished and verified in an independent feasibility study accomplished by the FluiDyne Corporation. Management approval to proceed with the modification of the existing 4-foot transonic tunnel to a 4-foot cryogenic tunnel (4-CWT) was given in mid-1976. This report reviews the work to date on the design, fabrication, and instrumentation of the DC-10 model to be used in the verification test of the McDonnell Douglas 4-foot Cryogenic Transonic Wind Tunnel.

*Douglas Aircraft Co., McDonnell Douglas Corp., 3855 Lakewood Blvd., Long Beach, CA 90846 U.S.A.

129. *Aldrich, J. F. L.: **Progress Report on the Douglas Four-Foot Cryogenic Wind Tunnel.** Paper no. 35, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 6 pp.

A80-24086#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

The Douglas design effort toward a cryogenic operating mode of their intermittent 4-foot wind tunnel began in August 1976 under the leadership of NASA Langley. The preliminary study had concluded it was feasible, the cost was reasonable for the Reynolds number gain, but certain scaled tests should be made to minimize risk. This paper summarizes the experimental program. The design of the modifications on the 4-Foot Cryogenic Wind Tunnel (4-CWT) began with the completion of the 1-Foot Cryogenic Wind Tunnel (1-CWT) design and continued in parallel with the experimental program. About 85 percent of the design has been completed. Approximately 165 drawings have been released. The remaining design work includes stings, calibration equipment, control sensor installation, and interconnections to operating console and computer. The majority of the supplier-fabricated items have been delivered. Modifications and installation work by the contractors are expected to be completed in August, at which time prerun checkout of the tunnel subsystem will begin and build up to check runs of the total system at ambient and cryogenic temperatures about October.

*Douglas Aircraft Co., McDonnell Douglas Corp., 3855 Lakewood Blvd., Long Beach, CA 90846 U.S.A.

130. *Clark, P. J. F.; and **Morel, J. P.: **Circuit Optimization Study for the European Transonic Windtunnel.** Paper no. 36, 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979, 10 pp., 9 refs.

A80-24101#

Note: For the complete compilation of papers, see citation no. [174] in this bibliography.

An Airline Optimization Study defines the most economical circuit configuration for the European Transonic Windtunnel (ETW) based on the combination of capital and operating costs consistent with flow quality, test spectrum, and operational flexibility requirements. This study included looking at the sensitivity of the optimum configuration to variations in the factors which affect the cost of the various components or cost elements over a reasonable range.

*Dilworth Secord Meagher & Associates, Ltd. (DSMA), 10 Park Lawn Road, Toronto, Ontario M8Y 3H8, Canada
*Technical Group ETW, c/o National Aerospace Laboratory, 1006 BM Amsterdam The Netherlands

131. *Hall, R. M.: **Onset of Condensation Effects With an NACA 0012-64 Airfoil Tested in the Langley 0.3-Meter Transonic Cryogenic Tunnel.** NASA TP-1385, April 1979, 70 pp., 23 refs. Formerly published as NASA TM-78666.

N79-22043#

A 0.137-m NACA 0012-64 airfoil has been tested at 0° angle of attack in the nitrogen-gas NASA Langley 0.3-m Transonic Cryogenic Tunnel at free-stream Mach numbers of 0.75, 0.85, and 0.95 over a total-pressure range from 1.2 to 5.0 atm. The onset of condensation effects as determined by varying stagnation temperature was found to correlate better with the amount of supercooling in the free stream than it did with the supercooling in the region of maximum local Mach number over the airfoil. Effects in the pressure distribution over the airfoil were generally seen to appear over its entire length at nearly the same total temperature. Both observations suggest that heterogeneous nucleation does occur in the free stream. The present results are compared to calculations made by Sivier and data gathered by Goglia. The potential operational benefits realized from supercooling are presented in terms of increased Reynolds number capability at a given tunnel total pressure and reduced drive-fan power and liquid nitrogen consumption if Reynolds number is held constant. Depending on total pressure and free-stream Mach number, these three benefits are found to vary respectively from 8 to 19 percent, 12 to 24 percent, and 9 to 19 percent. An appendix is included which gives details of the data analysis and error estimates for the differences in pressure distributions.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

132. *Blanchard, A.; and *Dor, J.-B.: **Dynamic Tests Carried Out in the T'2 Cryogenic Wind Tunnel to Determine the Effects of Variation in Liquid Nitrogen Injection.** Rep. DCAF F070143; DERAT-5/5007-DY; CRF/5007-AYD, April 1979, 95 pp., 5 refs. English text.

N87-70318

The T'2 wind tunnel and its ancillary equipment are first described. The chosen operating procedure is presented for a typical cryogenic run. The behavior of the liquid nitrogen during the injection and the instantaneous nitrogen flow rates given by a quick move of the control valve were carefully studied. Results of the experimental dynamic tests obtained are discussed. The heat-transfer computation for a thin copper plate at the test-section wall is compared with experimental results. The dynamic results obtained in the present configuration will be valid for other types of injector and will be a guide in optimizing the liquid nitrogen injection.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

133. *Albone, C. M.: **An Investigation into the Real Gas Effects of Cryogenic Nitrogen in Inviscid Homentropic Flow.** R.A.E. TM Aero 1805, May 1979, 17 pp., 5 refs.

N80-21611#

Note: A shortened version of this Memorandum (citation no. [111] in this bibliography) was presented at the First International Symposium on Cryogenic Wind Tunnels at Southampton University, April 3-5, 1979.

As a contribution to the study of the suitability of using cryogenic nitrogen as the test gas in a high-Reynolds-number transonic wind tunnel, a study is made here of the real-gas effects of nitrogen at low temperatures. The study, limited to inviscid homentropic flow of a nonconducting gas, takes the form of an independent confirmation of results by Kilgore et al. A recent paper by Wagner and Schmidt on this subject uses a different equation of state from that used here and their studies cover more than just homentropic flow. The new contribution in this Memorandum is that the use of a simplified equation of state enables an expression for enthalpy (and, hence, the terms in Bernoulli's equation) to be derived by analytic integration.

*Royal Aircraft Establishment, Farnborough, Hants GU14 6TD, England

134. *Hall, R. M.: **Onset of Condensation Effects as Detected by Total Pressure Probes in the Langley 0.3-Meter Transonic Cryogenic Tunnel.** NASA TM-80072, May 1979, 51 pp., 9 refs.

N79-27094#

Total-pressure probes mounted in the test section of the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) were used to detect the onset of condensation effects for free-stream Mach numbers of 0.50, 0.75, 0.85, and 0.95 and for total pressures between 1 and 5 atm. The amount of supercooling is found to be about 3 K and suggests condensation is occurring on pre-existing liquid nitrogen droplets resulting from incomplete evaporation of the liquid nitrogen injected to cool the tunnel. The liquid nitrogen injection process presently used for the 0.3-m TCT results in a wide spectrum of droplet sizes being injected into the flow. Since the relatively larger droplets take much more time to evaporate than the more numerous smaller droplets, the larger ones reach the test section first as the tunnel operating temperature is reduced. However, condensation effects in the test section are not immediately measurable because there is not a sufficient number of the larger droplets to have an influence on the thermodynamics of the flow.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

135. *Bursik, J. W.; **Hall, R. M.; and **Adcock, J. B.: **A Two-Phase Mach Number Description of the Equilibrium Flow of Nitrogen in Ducts.** Presented at the AIAA 14th Thermophysics Conference, June 4-9, 1979, Orlando, Florida, 10 pp., 10 refs.

AIAA 79-1051 A79-38034#

For equilibrium two-phase flow the squared ratio of mixture specific volume to mixture sound speed, $\beta(g,T)$, is shown to have the same form as many weighted mean two-phase properties; namely, $\beta\text{-}(g,T) = g\beta(1,T)+(1-g)\beta(O,T)$ where g is the liquid mass fraction and $\beta(1,T)$ and $\beta(O,T)$ are the isothermal saturated liquid and vapor values of β which are generated for nitrogen in tabulated form by a computer program. With these β-tables, a simplified method of calculating two-phase Mach numbers is developed for various duct flows. One- and two-phase Mach number jumps at phase boundaries are also discussed.

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**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

136. *Ray, E. J.; *Ladson, C. L., *Adcock, J. B.; *Lawing, P. L.; and *Hall, R. M.: **Review of Design and Operational Characteristics of the 0.3-Meter Transonic Cryogenic Tunnel.** NASA TM-80123, September 1979, 56 pp., 17 refs. Also presented at the 1st Int. Symp. on Cryogenic Wind Tunnels, Southampton, England, April 3-5, 1979 (Citation no. [122] in this bibliography).

N79-32159#

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

137. *Goodyer, M. J.: **Cryogenic Wind Tunnel Activities at the University of Southampton.** NASA CR-159144, September 1979, 10 pp., 5 refs.

N80-10231#

This paper describes the characteristics and behavior of a 0.1-m transonic cryogenic wind tunnel. The wide band of usable Reynolds numbers is analyzed along with a flow-visualization technique using propane. The combination of magnetic suspension with the cryogenic wind tunnel is described. An outline of the circuit showing the locations of the magnet system and the features of the tunnel is presented.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England
NASA grant NSG-7523

138. *Kilgore, R. A.: **Evolution of the Cryogenic Wind Tunnel and Experience With the Langley 0.3-m Transonic Cryogenic Tunnel.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 3-48, 31 refs. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

This paper traces some of the key events in the evolution of the cryogenic wind tunnel leading up to the decision in the United States to build the National Transonic Facility (NTF), the first major wind tunnel especially designed to take advantage of cryogenic operation. The NTF, which is the subject of this conference, will close the Reynolds number gap. It will also provide for the exploitation of other unique research capabilities made possible by cryogenic operation. A brief overview is given of the cryogenic wind-tunnel projects around the world to illustrate the profound impact the cryogenic tunnel concept is having on wind-tunnel development. This paper also reviews some of our experiences with the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT), the tunnel in which we verified the cryogenic wind-tunnel concept at transonic speeds; thereby making possible the decision to build the NTF.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

139. *Howell, R. R.: **Overview of Engineering Design and Operating Capabilities of the National Transonic Facility.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 49-75. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

This paper gives an overview of the engineering design of the U.S. National Transonic Facility (NTF). The overview includes a summary of the design goals and criteria, pertinent design details, and projected performance. The NTF will afford the nation a markedly improved capability to test at or near full-scale Reynolds number and to assess the effects of Reynolds number, Mach number, and model deformation on the aerodynamics of configurations.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

140. *Bower, R. E.: **Use of the National Transonic Facility as a National Testing Facility.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 79-92, 1 ref. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

Special capabilities of the NTF are reviewed to encourage potential users to start planning for future tests. Specific areas of research and development are suggested. User concerns, such as tunnel productivity, data quality, and procedures for proposing specific experiments are discussed. Participation by the scientific community in this opportunity for transonic research is encouraged and mechanisms for implementation are offered.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

141. *Mershon, F. E.: **Overview of Structural and Mechanical Session.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 95-99, 1 ref. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

The NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) and the U.S. National Transonic Facility (NTF) have been described previously in this conference. This session will show examples of how the temperature range of the tunnel gas, 78 to 353 K (140 to 635 °R), affected the design and development of structural and mechanical components and will provide a detailed description of four major developmental areas.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

142. *Ramsey, J. W., Jr.: **Design for Thermal Stress.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 101-119. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

The large cryogenic wind-tunnel structures inside the U.S. National Transonic Facility (NTF) were analyzed and designed for mechanical plus thermal stresses. The MITAS and SPAR computer programs were used to solve the large, forced convection (up to a 700 to 1 ratio) driven, thermal stress problem. To prevent overstressing, yielding, and fatiguing, structural criteria were developed. All requirements from the criteria imposed on these structures have been exceeded. An analysis and design procedure was developed with two large internal structures used to demonstrate this procedure. Several design approaches to reduce high-thermal stresses are presented.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

143. *Lassiter, W. S.: **Noise Attenuation in a Pressurized, Cryogenic Environment.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 121-137, 4 refs. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

Tests at ambient and cryogenic temperatures showed the adhesive material used to bond the resonator system together retained shear, tensile, and fatigue properties at cryogenic temperatures. An attenuation test resulted in good agreement between experiment and theory in determining the attenuation of a prototype dual resonator panel.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

144. *Joplin, S. D.: **Status Report on Development of Large Seals for Cryogenic Applications.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 139-155. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

Several parameters have been identified that influence seal performance including surface finish, spring and pressure activation, seal fit in the groove, and treatments to the sealing surface with polymer tapes. Tests are in progress to establish the seal performance with lubricants, with bonded joints, and for a radial installation. Tests will also be made to establish that the seals will seal at cryogenic temperatures and will seal variable gaps during a thermal cycle.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

145. *Wingate, R. T.: **Design of Compressor Fan Disks for Large Cryogenic Wind Tunnels.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 157-176, 5 refs. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

A number of general, practical design considerations in the design of a large fan disk for a transient cryogenic environment arose out of the U.S. National Transonic Facility (NTF) fan disk design studies. Highlights of these considerations, including design philosophy and factors influencing the geometry or external profile, are discussed. Specific features of the NTF fan disk design are also presented as an example of a compromise design resulting from tradeoffs between these competing factors.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

146. *Bruce, W. E., Jr.: **Systems Design Session–Overview.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 179-184. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

The previous paper by Howell (citation no. [139] in this bibliography) gave an overview of the various systems of the tunnel and described the basic operations of each. In this session, the focus will be on the systems designed to control fluids and energy which are affected by the cryogenic test gas and/or the cryogenic operation of the tunnel.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

147. *Watson, N. D.; and *Williams, D. E.: **Development of an Internal Thermal Insulation System for the National Transonic Facility.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 185-221. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

This paper presents the results of a design to provide a cost effective and reliable insulation system for the pressure shell of the U.S. National Transonic Facility (NTF). Critical factors affecting the choice of internal insulation instead of an external insulation system are discussed. Design criteria established for the internal insulation system are presented.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

148. *Kelsey, E. L.; and *Turner, R. D.: **Connectors and Wiring for Cryogenic Temperatures.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 223-233. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

Electrical connectors and wiring insulation exposed to cyclic cryogenic thermal environment are subject to cyclic stresses which can lead to cracking and failure of these components. This paper describes a series of tests to qualify connectors and wiring for the transient thermal environment of the U.S. National Transonic Facility (NTF).

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

149. *Kirby, C. E.: **Status of Mathematical Modeling of National Transonic Facility Fluid Dynamic Processes.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 235-247. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

The theoretical basis of the four different approaches being used for mathematical modeling of the U.S. National Transonic Facility (NTF) is summarized in this paper along with results of limited experimental verification tests. Qualitative discussions are presented on the fan and plenum/slotted-wall test section performance and cross-coupling effects between temperature, pressure, and Mach number. Calculated results from the computer model for commanded changes in set points are also presented.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

150. *Osborn, J. A.: **A Description of the National Transonic Facility Process Control System.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 249-258, 1 ref. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

High productivity and energy efficiency have been emphasized in the design of the U.S. National Transonic Facility (NTF). To support these goals, a three-level hierarchical control system has been designed to provide fast response, flexibility, and automation. The control system uses dedicated analog controllers, individual digital microcomputers, and a large supervisory computer. Standard commercial hardware is used throughout.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

151. *Buckley, J. D.; and *Sandefur, P. G., Jr.: **Development of Joining Techniques for Finned Tube Heat Exchanger for a Cryogenic Environment.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 259-269, 4 refs. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

Three joining methods were considered for use in fabricating cooling coils for the U.S. National Transonic Facility (NTF). Results of evaluation tests are presented.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

152. *Ivey, G. W., Jr.: **Cryogenic Gaseous Nitrogen Discharge System.** Cryogenic Technology, NASA CP-2122, Pt. I, March 1980, pp. 271-278, 2 refs. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#

Note: For the complete conference, see citation no. [185] in this bibliography.

A discharge system for dispersing the gaseous nitrogen exhaust of the U.S. National Transonic Facility (NTF) into the atmosphere is described.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

153. *Guarino, J. F.: **Instrumentation Systems for the National Transonic Facility–Overview.** Cryogenic Technology, NASA CP-2122, Pt. II, March 1980, pp. 281-286. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20358#

Note: For the complete conference, see citation no. [185] in this bibliography.

Instrumentation and measurement systems are important elements in any complex research facility. The U.S. National Transonic Facility (NTF) with its unique operational characteristics is clearly a complex facility and, as such, represents a significant challenge to wind-tunnel instrument designers. This paper briefly describes the instrument requirements imposed by the new testing environment, the instrument systems being provided for facility calibration and operation, and the research and development activities directed at meeting overall instrument and measurement requirements.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

154. *Bryant, C. S.: **The National Transonic Facility Data System Complex.** Cryogenic Technology, NASA CP-2122, Pt. II, March 1980, pp. 287-297, 2 refs. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20358#

Note: For the complete conference, see citation no. [185] in this bibliography.

The U.S. National Transonic Facility (NTF) Data System Complex will consist of four central processing units configured in a fully connected, distributed network. Each of the four computer systems and the associated analog and digital data acquisition, recording, control, and display equipment are described and functional capabilities outlined.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

155. *Ferris, A. T.: **Cryogenic Wind Tunnel Force Instrumentation.** Cryogenic Technology, NASA CP-2122, Pt. II, March 1980, pp. 299-315. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20358#

Note: For the complete conference, see citation no. [185] in this bibliography.

NASA Langley Research Center has developed one-piece strain-gage force balances for use in cryogenic wind tunnels. This was done by studying the effect of the cryogenic environment on materials, strain gages, cements, solders, and moisture-proofing agents, and selecting those that minimized strain-gage output changes due to changes in temperature. Wind-tunnel results obtained from the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) were used to verify laboratory test results.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

156. *Mitchell, M.: **Pressure Measurement System for the National Transonic Facility.** Cryogenic Technology, NASA CP-2122, Pt. II, March 1980, pp. 317-327, 3 refs. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20358#

Note: For the complete conference, see citation no. [185] in this bibliography.

Over the last 4 years, the Electronically Scaled Pressure (ESP) Measurement System has been developed at the NASA Langley Research Center with the primary objective being to satisfy the pressure measurement requirements of the U.S. National Transonic Facility (NTF). The system is capable of making a large number of pressure measurements simultaneously. The ESP system has undergone an extensive field evaluation and the overall results show that the ESP system can make measurements within 0.25 percent of full scale in a liquid nitrogen environment provided the module is contained in a temperature controlled enclosure (currently under development), maintained at a constant temperature, and the system is calibrated immediately before each measurement. The system is also compatible with the distributed processing concept.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

157. *Finley, T. D.: **Model Attitude Measurements in the National Transonic Facility.** Cryogenic Technology, NASA CP-2122, Pt. II, March 1980, pp. 329-341. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20358#

Note: For the complete conference, see citation no. [185] in this bibliography.

The U.S. National Transonic Facility (NTF) has established a requirement for the precise measurement of model pitch and roll. Two approaches to this problem are being explored. The conventional approach to model attitude measurements at the NASA Langley Research Center involves the use of precision accelerometers to detect the attitude of the model with respect to the local vertical. Testing has indicated that this technique can be used in the NTF with only a slight degradation in accuracy. A problem which persists when using accelerometers is that of response. The slow response of this type of measurement system has forced us to consider the use of an optical measurement system. We are studying, under contract, the problems associated with using an interferometric angle measurement system in the NTF environment. This paper describes the work done to date on both these approaches.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

158. *Germain, E. F.: **Temperature Instrument Development for a Cryo Wind Tunnel.** Cryogenic Technology, NASA CP-2122, Pt. II, March 1980, pp. 343-351. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20358#

Note: For the complete conference, see citation no. [185] in this bibliography.

This paper reviews the development work which extended conventional wind-tunnel thermometry into the cryogenic wind-tunnel range. The emphasis is on stagnation temperature measurements where a mix of platinum resistance thermometers and thermocouples is necessary to satisfy all requirements. Calibration and thermocouple homogeneity test equipment are described.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

159. *Holmes, H. K.: **Model Deformation Measurements in the National Transonic Facility.** Cryogenic Technology, NASA CP-2122, Pt. II, March 1980, pp. 353-361, 1 ref. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20358#

Note: For the complete conference, see citation no. [185] in this bibliography.

Four measurement approaches are discussed: stereo photogrammetry, scanning stereo photogrammetry, Moiré topography, and microwave modulated laser beams. Several problem areas which must be accommodated; sensor motion, target mounting, surface constraints, and computational complexities, have been identified.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

160. *Young, C. P., Jr.: **Cryogenic Models/Sting Technology Session–Overview.** Cryogenic Technology, NASA CP-2122, Pt. II, March 1980, pp. 365-371, 6 refs. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20358#

Note: For the complete conference, see citation no. [185] in this bibliography.

The advent of high-Reynolds-number high-dynamic-pressure testing in a cryogenic environment offers exciting and difficult challenges for the researcher and the model/sting systems design engineers. Although much experience has been obtained in the use of the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT), new technology is required for the design and fabrication of models/stings for testing at high Reynolds numbers and high pressures in the new U.S. National Transonic Facility (NTF). The technology activities reported in this overview are just getting underway at NASA Langley Research Center and are expected to be a continuing effort until the NTF is operational. The papers selected for publication in this session of the proceedings represent the experience obtained to date and reflect the areas of work we believe to be of primary interest to potential users of the NTF.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

161. *McKinney, L. W.: **Considerations in the Selection of the Pathfinder Model Configurations.** Cryogenic Technology, NASA CP-2122, Pt. II, March 1980, pp. 373-381, 1 ref. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20358#

Note: For the complete conference, see citation no. [185] in this bibliography.

An advanced transport and a highly-maneuvering fighter configuration have been selected as initial models for the cryogenic high-dynamic pressure model technology development program. These models will provide a basis for establishing practical achievable Reynolds number boundaries based on the model stresses and model/balance/sting system dynamics. The model loads, thus the stresses, will be constant in the NTF when matching full scale airplane Reynolds numbers over the altitude range at a constant load factor. The maximum Reynolds number obtainable under these conditions will be limited by the influence of dynamic pressure on model/balance/sting system dynamics. Reynolds numbers to 25 million, based on chord, can be obtained on the Pathfinder models in the NTF with no increase in loads over those in existing tunnels. These models represent advanced technology configurations and will be used for parametric research studies.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

162. *Gloss, B. B.: **Some Aerodynamic Considerations Related to Surface Definition.** Cryogenic Technology, NASA CP-2122, Pt. II, March 1980, pp. 383-393, 9 refs. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20358#

Note: For the complete conference see citation no. [185] in this bibliography; for a later version of this paper see citation no. [222] in this bibliography.

The requirement for high-quality test data from the U.S. National Transonic Facility (NTF) and the high-Reynolds-number capability of the NTF have caused NASA to reexamine the areas of model fabrication tolerances, model surface finish, and orifice-induced pressure error. This paper describes the results of this reexamination and planned research programs to extend the data base.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

163. *Bradshaw, J. F.; and *Lietzke, D. A.: **Pathfinder I Model.** Cryogenic Technology, NASA CP-2122, Pt. II, March 1980, pp. 395-410, 3 refs. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20358#

Note: For the complete conference see citation no. [185] in this bibliography.

This paper describes the Pathfinder I Model that has been designed for testing in the U.S. National Transonic Facility (NTF). Unique considerations for the design of cryogenic models are discussed along with the particular design requirements for Pathfinder I. The geometric details of the model are provided and various features of the model components are discussed, along with a description of design validation test support activities. Also, data are presented which emphasize the importance of material selection as it influences the model test program because of material property changes with temperature. It is found that good engineering practice, with proper consideration given to the cryogenic environment and specific test requirements, will produce a model acceptable for testing in the NTF.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

164. *Hunter, W. F.: **Analysis and Testing of Model/Sting Systems.** Cryogenic Technology, NASA CP-2122, Pt. II, March 1980, pp. 411-422, 5 refs. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20358#

Note: For the complete conference see citation no. [185] in this bibliography.

This paper presents the analysis and testing approach for model/-sting systems being designed for the U.S. National Transonic Facility (NTF). Principal areas of analysis are discussed along with the development of mathematical models that are being used for various analyses. The interrelation and importance of rigorous analysis and verification testing in the design of model/sting systems for cryogenic, high-Reynolds-number testing are emphasized. The ongoing analysis and verification testing applications to the design of the first developmental model, Pathfinder I, are described and some preliminary results are given.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

165. *Hudson, C. M.: **Material Selection for the Pathfinder I Model.** Cryogenic Technology, NASA CP-2122, Pt. II, March 1980, pp. 423-441, 6 refs. Presented November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20358#

Note: For the complete conference see citation no. [185] in this bibliography.

The extremely low temperatures (approximately 78 K) in the U.S. National Transonic Facility (NTF) can significantly reduce the fracture toughness of many of the materials which might be used in constructing wind-tunnel models. Conversely, high fracture toughness is essential for the first model to be tested in the NTF (the so-called Pathfinder I model) because the stresses near structural discontinuities are quite high. These high stresses, if applied to relatively low toughness materials, would result in unacceptably small critical flaw sizes. To preclude the possibility of developing such small critical flaws (which would be difficult to detect), a materials survey was made to determine which materials had adequate strength and toughness at 78 K (140 °R) to be considered for model construction. The Fracture and Deformation Division of the National Bureau of Standards developed a preliminary list of candidate materials. NASA Langley personnel later expanded this list to include several additional materials. NASA Langley personnel further developed a series of factors which governed the selection of the materials for model fabrication. These factors included strength properties, fracture toughness, availability, corrosion resistance, machinability, cost, and delivery. The weldability of the material was not an important factor for this model since no structural welding will be done. This paper presents the results of the studies to select an optimum material for Pathfinder I.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

166. *Kilgore, R. A.: **Development of the Cryogenic Tunnel Concept and Application to the U.S. National Transonic Facility.** Paper no. 2 in AGARDograph no. 240, "Towards New Transonic Windtunnels", November 1979, 27 pp., 38 refs.

N80-19139#

Based on theoretical studies and experience with a low-speed fan-driven tunnel and with a pressurized transonic tunnel, the cryogenic wind-tunnel concept has been shown to offer many advantages with respect to the attainment of full-scale Reynolds number at reasonable levels of dynamic pressure in a ground-based facility. The unique modes of operation available in a pressurized cryogenic tunnel make possible for the first time the separation of Mach number, Reynolds number, and aeroelastic effects. By reducing the drive-power requirements to a level where a conventional fan-drive system may be used, the cryogenic concept makes possible a tunnel with high productivity and run times sufficiently long to allow for all types of tests. It does this at reduced capital costs and, for equal amounts of testing, reduced total energy consumption in comparison with other tunnel concepts. A new fan-driven high-Reynolds-number transonic cryogenic tunnel is under construction in the United States at the NASA Langley Research Center. The tunnel, to be known as the U.S. National Transonic Facility (NTF), has a 2.5 by 2.5 m test section and is capable of operating from ambient to cryogenic temperatures at stagnation pressures up to 8.8 atm. By taking full advantage of the cryogenic concept, the NTF will provide an order of magnitude increase in Reynolds-number capability over existing tunnels in the United States.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

167. *Hartzuiker, J. P.; **Christophe, J.; ***Lorenz-Meyer, W.; ****Pugh, P. G.: **The Cryogenic Windtunnel; Another Option for the European Transonic Facility.** Paper no. 3 in AGARDograph no. 240, "Towards New Transonic Windtunnels", November 1979, 15 pp., 34 refs.

N80-19140#

A new option for the proposed European Transonic Windtunnel is described: a cryogenic tunnel with test-section dimensions compatible with existing major European transonic tunnels. The tunnel performance is to the functional specification of the LaWs Group (Reynolds number based on mean aerodynamic chord variable between 25 and 40 million). The advantages and drawbacks of cryogenic testing as well as fundamental aspects of cryogenic aerodynamics are discussed. Comparative estimates for capital and operating costs are presented.

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**ONERA, B.P. 72, F-92322 Châtillon Cedex, France
***DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG
****Royal Aircraft Establishment, Bedford, Beds MK41 6AE, England

168. *Balakrishna, S.: **Synthesis of a Control Model for a Liquid Nitrogen Cooled, Closed Circuit, Cryogenic Nitrogen Wind Tunnel and its Validation.** Progress Report, period ending September 1979. NASA CR-162508, November 1979, 142 pp., 14 refs.

N80-13058#

Note: See also citation no. [210] in this bibliography.

This paper gives details of the efforts to synthesize a control-compatible multivariable model of a liquid nitrogen cooled, gaseous nitrogen operated, closed circuit, cryogenic pressure tunnel. The synthesized model was transformed into a real-time cryogenic tunnel simulator, and this model is validated by comparing the model responses to the actual tunnel responses of the 0.3-m Transonic Cryogenic Tunnel using the quasi-steady-state and the transient responses of the model and the tunnel. The global nature of the simple, explicit, lumped multivariable model of a closed circuit cryogenic tunnel is demonstrated. This report details the modeling phase of the project "Modeling and Control of Transonic Cryogenic Tunnel" sponsored by NASA Langley Research Center under grant NSG 1503 which was performed during the period ending September 1979. The scope of this report is confined to model synthesis and its validation. Preliminary findings on this modeling activity were reported at the First International Symposium on Cryogenic Wind Tunnels which was held at University of Southampton, England, in April 1979.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.
NASA Grant NSG-1503

169. *Younglove, B. A.; and *McCarty, R. D.: **Thermodynamic Properties of Nitrogen Gas Derived from Measurements of Sound Speed.** NASA RP-1051, December 1979, 53 pp., 12 refs. Also NBSIR 79-1611.

N80-14257#

A virial equation of state for nitrogen has been determined using newly measured speed-of-sound data and existing pressure-density-temperature data in a multiproperty-fitting technique. The experimental data taken were chosen to optimize the equation of state for a pressure range of 0 to 10 atm and for a temperature range of 60 to 350 K. Comparisons are made for thermodynamic properties calculated both from the new equation and from existing equations of state.

*National Bureau of Standards, Boulder Laboratories, Boulder, CO 80302 U.S.A.
Funded by NASA Langley Research Center, Hampton, VA U.S.A.

170. *Johnson, W. G., Jr.; and *Igoe, W. B.: **Aerodynamic Characteristics at Low Reynolds Numbers of Several Heat-Exchanger Configurations for Wind Tunnel Use.** NASA TM-80188, December 1979, 54 pp., 3 refs.

N80-14046#

In response to design requirements of the U.S. National Transonic Facility, aerodynamic tests were made to determine the pressure-drop, flow uniformity, and turbulence characteristics of various heat-exchanger configurations as a function of Reynolds number. Data were obtained in air with an indraft flow apparatus operated at ambient temperature and pressure. The unit Reynolds number of the tests varied from about 0.06 million to about 1.3 million per meter. The test models were designed to represent segments of full-scale tube bundles and included bundles of round tubes with plate fins in both staggered and inline tube arrays, round tubes with spiral fins, elliptical tubes with plate fins, and an inline grouping of tubes with segmented fins.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

171. *Mueller, M. H.; *Clausing, A. M.; *Clark, G. L., Jr.; *Weiner, J. G.; and *Kempka, S. N.: **Description of UIUC Cryogenic Wind Tunnel Including Pressure Distributions, Turbulence Measurements and Heat Transfer Data.** Univ. of Ill., Tech. Rep. ENG-70-4013, <u>December 1979</u>, 91 pp., 18 refs.

N82-77683#

The UIUC cryogenic heat-transfer tunnel is a low-speed closed-circuit wind tunnel with a rectangular test section. Cooling is achieved by the use of liquid nitrogen and the tunnel can be operated anywhere between 80 and 300 K. Different types of tests were made to qualify the wind tunnel by comparing results obtained with well documented work. Results are given and discussed. Models used are described. The wind tunnel proved to be a satisfactory means of studying heat-transfer phenomena.

*University of Illinois at Urbana-Champaign, Urbana, IL 61801 U.S.A.

172. *Green, J. E.; and *Taylor, C. R.: **Enhancement of the ETW Operating Envelope by Increasing Maximum Pressure and Power.** RAE-TM Aero 1827, <u>December 1979</u>, 29 pp., 11 refs.

NASA Langley Technical Library Number CN-154941

This memorandum considers the potential for improving the ability of the European Transonic Windtunnel (ETW) to simulate full-scale flight conditions, for a relatively modest increase in cost, by increasing the strength of the pressure shell and slightly augmenting the power of the main drive relative to the values required to meet the AGARD LaWs specification. The question of increasing the size of the tunnel, to meet the LaWs requirements at a reduced pressure, is also addressed. This memorandum has been prepared by RAE, with the assistance from the ETW Technical Group in defining tunnel performance parameters, as a contribution to final discussions of the tunnel specification.

*Royal Aircraft Establishment, Farnborough, Hants GU14 6TD, England

173. *Kilgore, R. A.: **Wind Tunnel.** McGraw-Hill, <u>1979</u>, Yearbook of Science and Technology, pp. 413-415.

A way to improve Reynolds-number capability in wind tunnels has been provided by the development of tunnels capable of operating at cryogenic temperatures, with minimum temperatures near 77 K (-321 °F). Cooling the wind-tunnel test gas to cryogenic temperatures results in a large increase in Reynolds number without raising dynamic pressure, while reducing the tunnel drive-power requirements. The cryogenic concept is explained and several small cryogenic wind tunnels are described. The largest cryogenic tunnel is the U.S. National Transonic Facility (NTF) under construction at the NASA Langley Research Center. The NTF is designed to meet the high-Reynolds-number testing needs of the U.S.A.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

174. First International Symposium on Cryogenic Wind Tunnels. Held at the University of Southampton, England, April 3-5, 1979, 312 pp. (A80-24078–A80-24101#), <u>1979</u>, 312 pp.

TL567.W5I57,1979 A80-24077#

Note: The papers presented at this symposium are citation nos. [95 through 130] in this bibliography.

The first paper presented served as an introduction to the conference. The history of the development of cryogenic wind tunnels was given and suggestions made for future research to make tunnels of this kind even more valuable. Thirty-five additional papers were presented grouped under the following topics: instrumentation, cryogenic tunnels with magnetic levitation, liquid and gaseous-nitrogen flow properties, cryogenic tunnel technology, tunnel controls, heat-transfer topics, model design, and reports on tunnel projects. (Copies of the papers given at this Symposium are available from Dr. M. J. Goodyer, Dept. of Aeronautics & Astronautics, University of Southampton, Southampton SO9 5NH, Hampshire, England.)

175. *Blanchard, A.; *Dor, J.-B.; and *Breil, J. F.: **Mesures des Fluctuations de Temperature et de Pression dans la Soufflerie Cryogenique T'2.** (Toulouse) Rept. no. OA8/5007 and DERAT no. 8,5007 DN, <u>January 1980</u>, 22 pp., 19 figs., 9 refs.

Note: For an English translation and an abstract of this paper see citation no. [227] in this bibliography.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

176. *Dinguirard, M.; *Serrot, G.; *Duffaut, J.; *Blanchard, A.; *Dor, J.-B.; and *Breil, J. F.: **Etude Qualitative de l'Apparition du Broulillard d'Azote dans la Soufflerie Cryogenique a Induction T'2,** ONERA/CERT Rept. 1/6059, <u>February 1980</u>, 73 pp., 5 refs.

N81-19138#

Note: For an English translation and an abstract of this report see citation no. [220] in this bibliography.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

177. *Howell, R. R.: **The National Transonic Facility: Status and Operational Planning.** Presented at the AIAA 11th Aerodynamic Testing Conference, Colorado Springs, Colorado, <u>March 18-20, 1980</u>, 9 pp., 4 refs.

AIAA Paper 80-0415 A80-26930#

The construction of the U.S. National Transonic Facility (NTF) is advancing on schedule toward a target completion date in 1982. Several residual concerns remain which may emerge as problems in the operation of the facility. Among these are thermal stress constraints which may limit the rate at which temperatures can be changed; seal performance in a dynamic cryogenic environment which may result in undesirable internal flow leaks, and inadequate understanding of the detailed tunnel flow process which would result in inefficient process controls. The current design affords the capability of dealing with all of these concerns if they become problems. The outstanding instrument need is for a real-time model surface deformation measurement system. A program for the development of this instrument system is underway. The user access to the NTF has been addressed and a plan developed which will allow any qualified user access to the facility. The use of the NTF by organizations outside of NASA is encouraged. A practical look at the occupancy cost and the cost of liquid nitrogen for high-Reynolds-number tests indicates operating costs should not be an inhibiting factor in the use of the NTF.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

178. *Thibodeaux, J. J.; and **Balakrishna, S.: **Automatic Control of NASA Langley's 0.3-Meter Cryogenic Test Facility.** Presented at the AIAA 11th Aerodynamic Testing Conference, Colorado Springs, Colo., March 18-20, 1980, 15 pp., 3 refs. Also in Journal of Guidance and Control, vol. 4, no. 4, July-August 1981, pp. 428-432, 5 refs.

AIAA Paper 80-0416 A80-26931#

Experience during the past 6 years with the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) has shown that there are problems associated with efficient operation and control of cryogenic tunnels using manual control schemes. This is due to the high degree of process crosscoupling between the independent control variables (temperature, pressure, and fan drive speed) and the desired test condition of Mach number and Reynolds Number. One problem has been the inability to maintain long-term accurate control of the test parameters. Additionally, the time required to change from one test condition to another is excessively long and much less efficient than desirable in terms of liquid nitrogen and electrical power usage. For these reasons, we are making studies to (1) develop and validate a mathematical model of the 0.3-m TCT, (2) use this model in a hybrid computer simulation to design temperature and pressure feedback control laws, and (3) evaluate the adequacy of these control schemes by analysis of closed-loop experimental data. This paper presents the results of these studies.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
**Old Dominion University, Norfolk, VA 23508-0369 U.S.A.

179. *Johnson, C. B.: **A Study of Nonadiabatic Boundary-Layer Stabilization Time in a Cryogenic Tunnel for Typical Wing and Fuselage Models.** Presented at the AIAA 11th Aerodynamic Testing Conference, Colorado Springs, Colo., March 18-20, 1980, 9 pp., 10 refs.

AIAA Paper 80-0417 A80-26932#

Note: For a later version of this report see citation no. [264] in this bibliography.

We have made a theoretical study of the time varying effect of nonadiabatic wall conditions on boundary layer properties for a two-dimensional wing section and an axisymmetric body of revolution typical of a fuselage. The wing section and body of revolution are representative of the root chord and fuselage of what we consider to be a typical size transport model for the U.S. National Transonic Facility. We made the transient analysis for a Mach number of 0.85, for stagnation pressures of 2, 6, and 9 atm at several cryogenic values of total temperature for a solid wing, and for three different fuselage skin-thickness configurations. The analysis considered wing and fuselage sections made from stainless steel, beryllium copper, and aluminum. This paper gives examples that may be used to determine the total temperature.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

180. *Fancher, M. F.: **A Transonic, Cryogenic Wind Tunnel Test of a Supercritical Airfoil Model: Background and Progress.** Presented at the AIAA 11th Aerodynamic Testing Conference, Colorado Springs, Colo., March 18-20, 1980, 15 pp., 13 refs.

AIAA Paper 80-0418

A fourteen percent thick supercritical two-dimensional airfoil model is to be tested in April and May 1980, in the Douglas Aircraft Company blowdown one-foot cryogenic wind tunnel (1-CWT). The test is part of a program to develop testing methods and technology required for effective use of the blowdown Douglas Aircraft Company four-foot cryogenic wind tunnel (4-CWT), to become operational in September 1980. Cryogenic testing problems addressed by the test are discussed. This paper describes the test facility, model, and instrumentation.

*Douglas Aircraft Co., McDonnell Douglas Corp., 3855 Lakewood Blvd., Long Beach, CA 90846, U.S.A.

181. *Adcock, J. B.; and *Johnson, C. B.: **A Theoretical Analysis of Simulated Transonic Boundary Layers in Cryogenic-Nitrogen Wind Tunnels.** NASA TP-1631, March 1980, 37 pp., 12 refs.

N80-19131#

We have made a theoretical analysis to determine the real-gas effects on simulation of transonic boundary layers in wind tunnels with cryogenic nitrogen as the test gas. The analysis included laminar and turbulent flat-plate boundary layers and turbulent boundary layers on a two-dimensional airfoil. The results indicate boundary layers in such wind tunnels should not be substantially different from ideal-gas boundary layers at standard conditions. At a pressure of 9.0 atm, two separate effects produce deviations of real-gas values from ideal-gas values in the opposite direction from deviations at 1.0 atm and are of the same insignificant order of magnitude. Results also show nonadiabatic boundary layers should be adequately simulated if the enthalpy ratio is the correlating parameter rather than the temperature ratio.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

182. *Balakrishna, S.: **Automatic Control of Liquid Nitrogen Cooled, Closed-Circuit, Cryogenic Pressure Tunnel.** Progress Report for the period October 1979-March 1980. Submitted by the Old Dominion University Research Foundation, Norfolk, Va., NASA CR-162636, March 1980, 97 pp., 8 refs.

N80-22366#

This report details the control analysis phase of the project *Modeling and Control of Transonic Cryogenic Wind Tunnels*, sponsored by NASA Langley Research Center (LaRC). The contents of this report complement the modeling phase activity which as been reported as *Synthesis of a Control Model for a Liquid Nitrogen Cooled, Closed Circuit, Cryogenic Nitrogen Wind Tunnel and its Validation* (citation no. [168] in this bibliography). This report gives details of control law design, proof of its adequacy, microprocessor compatible software design, and electronic hardware realization and its successful performance on the 0.3-m Transonic Cryogenic Tunnel at NASA LaRC.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.
NASA Grant NSG-1503

183. *Bald, W. B.: **A Discussion Document on the Thermal Design of Force Balances for Cryogenic Wind Tunnels.** Rept. no. OUEL-1321/80, March 1980, 41 pp.

N81-24119#

The design performance and theory of unheated and heated balances are reviewed. As extensive strain-gage calibration is necessary for unheated balances, they are not considered as favorable as heated ones. Five heaters are used in the heated balance arrangement proposed. Their role is to compensate for conductive losses and to prevent and minimize convective losses. Finite element techniques are used, details being given about the appropriate computer packages. The results of preliminary temperature measurements made on a TEM 1004/101 half balance are given, the outputs from the thermocouples used being fed via simple conditioning amplifiers into a U.V. recorder. The results indicate further work is necessary to optimize design and performance.

*Oxford University, Department of Engineering Science, Parks Road, Oxford OX1 3PJ, England
Contract no. AT/2057/072/XR/AERO

184. *Liepmann, H. W.; *Black, R. E.; *Dietz, R. O.; *Kirchner, M. E.; and *Sears, W. R.: **National Transonic Facility: A Review of the Operational Plan. Final Report.** NASA-CR-163463, March 1980, 26 pp.

N81-20090#

The proposed National Transonic Facility (NTF) operational plan is reviewed. The NTF will provide an aerodynamic test capability significantly exceeding that of other transonic regime wind tunnels now available. A limited number of academic research programs that might use the NTF are suggested. It is concluded that the NTF operational plan is useful for management, technical, instrumentation, and model building techniques available in the specialized field of aerodynamic analysis and simulation. It is also suggested that NASA hold an annual conference to discuss wind-tunnel research results and to report on developments that will further improve the utilization and cost effectiveness of the NTF and other wind tunnels.

*National Academy of Sciences, National Research Council, Washington, D.C.
Contract NASW-2342

185. **Cryogenic Technology.** NASA CP-2122, Parts I and II, March 1980, 441 pp. A conference held November 27-29, 1979 at NASA Langley Research Center, Hampton, Va.

N82-20357#(Pt.I)
N82-20358#(Pt.II)

Note: Selected papers from this conference are citation nos. [138 through 165] in this bibliography.

The proceedings of the NASA conference, held in November 1979, contain 29 papers which address different engineering problems associated with the design of mechanisms and systems to operate in a cryogenic environment. The focal point for the entire engineering effort was the design of the U.S. National Transonic Facility (NTF), a closed-circuit cryogenic wind tunnel. The papers covered a variety of subjects including thermal structures, insulation systems, noise, seals, controls, instrumentation, and materials. Papers also addressed design, fabrication, and instrumentation problems for models to be tested in a cryogenic wind tunnel. The general areas covered by sessions were (1) Overviews, (2) Mechanical/Structural Design, (3) Systems Design, (4) Instrumentation, and (5) Model/Sting Technology. Selected items follow in this bibliography.

186. *Adcock, J. B.: **Simulation of Flat-Plate Turbulent Boundary Layers in Cryogenic Tunnels.** Journal of Aircraft, vol. 17, April 1980, pp. 284-285, 11 refs.

A80-28855#

We have studied the magnitudes of real-gas effects on flat-plate turbulent boundary layer simulations in a cryogenic nitrogen wind tunnel to determine the validity of the method used by Inger (citation no. [81] in this bibliography) to estimate real-gas effects. Boundary-layer solutions for real gases, ideal gases with a specific heat ratio of 1.6, and ideal diatomic gases (specific heat ratio 1.4) were obtained for the worst case conditions of maximum stagnation pressure (9 atm), minimum stagnation temperature (120 K), and Mach number of 1.2. Calculated boundary-layer parameters such as friction coefficient and displacement thickness are shown to agree closely for the real gas and the ideal diatomic gas (specific heat ratio 1.4), while the ideal-gas solution used by Inger is shown to differ considerably from the real-gas values. Our results indicate real-gas effects on a flat-plate turbulent boundary-layer simulation in a cryogenic nitrogen tunnel are insignificant, and suggest the large real-gas effects reported by Inger for turbulent boundary layer shock interactions do not exist.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

187. *Goodyer, M. J.: **The Principles and Applications of Cryogenic Wind Tunnels.** Presented as Paper no. 1 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 6 pp., 3 refs.

N81-11049#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

A description of the background to the emergence of the cryogenic wind tunnel leads to discussions of its advantages compared with other means for raising the values of test Reynolds number to full scale. An introduction to the basic aero- and thermodynamics of wind-tunnel testing allows quantification of the advantages of low temperature in low speed and in transonic testing. Attention is drawn to secondary advantages unique to this tunnel and to the potentials of unconventional test gases. Descriptions are included of current types and applications of cryogenic wind tunnels.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

188. *Scurlock, R. G.: **Cryogenic Engineering I.** Presented as Paper no. 2 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and

May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 9 pp.

N81-11050#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

Subjects covered in this lecture include the following: basic properties of liquid nitrogen, oxygen, and air; and control of heat fluxes, insulation techniques, and low-loss storage.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

189. *Scurlock, R. G.: **Cryogenic Engineering II.** Presented as Paper no. 3 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 7 pp.

N81-11051#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

Subjects covered in this lecture include the following: thermal properties of commercial materials; instrumentation, including thermometry, flow, and pressure; and avoidance of two-phase flow.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

190. *Wigley, D. A.: **Properties of Materials: The Physical Properties of Metals and Non-Metals.** Presented as Paper no. 4 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 10 pp., 26 refs.

N81-11052#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

Subjects covered in this lecture include the following: the effect of temperature on the mechanical and physical properties of metals, including strength and toughness; and failure mechanism, influence of cracks and flaws, and fracture toughness.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

191. *Hall, R. M.: **Real-Gas Effects I–Simulation of Ideal Gas Flow by Cryogenic Nitrogen and Other Selected Gases.** Presented as Paper no. 5 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 16 pp., 12 refs.

N81-11053#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

The thermodynamic properties of nitrogen gas do not thermodynamically approximate an ideal, diatomic gas at cryogenic temperatures. Choice of a suitable equation of state to model its behavior is discussed and the equation of Beattie and Bridgeman is selected as best meeting the needs for cryogenic wind-tunnel use. The real-gas behavior of nitrogen gas is compared to an ideal, diatomic gas for the following flow processes: isentropic expansions, normal shocks, boundary layers, and shock-wave boundary-layer interactions. The only differences in predicted pressure ratio between nitrogen and an ideal gas that may limit the minimum operating temperatures of transonic cryogenic wind tunnels seem to occur at total pressures approaching 9 atm and total temperatures 10 K below the corresponding saturation temperature. Under these conditions, the differences approach 1 percent for both isentropic expansions and normal shocks. Several alternative cryogenic test gases–air, helium, and hydrogen–are also analyzed. Differences in air from an ideal, diatomic gas are similar in magnitude to those of nitrogen and should present no difficulty. However, differences for helium and hydrogen are over an order of magnitude greater than those for nitrogen or air. It is concluded that helium and hydrogen would not approximate the compressible flow of an ideal, diatomic gas.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

192. *Wigley, D. A.: **Properties of Materials: The Effect of Low Temperature on the Strength and Toughness of Materials.** Presented as Paper no. 6 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 24 pp., 30 refs.

N81-11054#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

Subjects covered in this lecture include the following: the effect of temperature on the mechanical and physical properties of nonmetals, including glasses, polymers, and composites; and sources of information.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

193. *Hall, R. M.: **Real Gas Effects II–Influence of Condensation on Minimum Operating Temperatures of Cryogenic Wind Tunnels.** Presented as Paper no. 7 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 21 pp., 27 refs.

N81-11055#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

Minimum operating temperatures of cryogenic wind tunnels are limited by real-gas effects. In particular, condensation effects are responsible for the minimum operating temperatures at total pressures up to about 9 atm. This paper reviews the two primary modes of condensation–homogeneous nucleation and heterogeneous nucleation–and the conditions with which either may limit minimum operating temperatures. Previous hypersonic and supersonic condensation data are reviewed as are data taken in the nitrogen-gas, NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT). Analysis of data in the 0.3-m TCT suggests we can approximate the onset of homogeneous nucleation using an analysis by Sivier and the onset of heterogeneous nucleation is only apparent just below free-stream saturation. Extension of the results from the 0.3-m TCT to other nitrogen-gas cryogenic tunnels is discussed and is shown to depend on length scales, purity of the liquid nitrogen injected for cooling, number of particulates in the flow, and the extent to which the injected liquid nitrogen is evaporated. From previous data, hybrid air-nitrogen tunnels are expected to realize little, if any, supercooling.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

194. *Scurlock, R. G.: **Cryogenic Engineering III.** Presented as Paper no. 8 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 6 pp., 4 refs.

N81-11056#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

Subjects covered in this lecture include the following: handling and transfer of liquid nitrogen; cooldown and thermal cycling problems; and safety, including asphyxia, cold burns, explosions, and fire hazards.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

195. *Kilgore, R. A.: **Model Design and Instrumentation Experiences With Continuous-Flow Cryogenic Tunnels.** Presented as Paper no. 9 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 22 pp., 25 refs.

N81-11057#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

The development of wind tunnels that can operate at cryogenic temperatures has placed several new demands on our ability to build and instrument wind-tunnel models. This lecture reviews some of the experiences at the NASA Langley Research Center relative to the design and instrumentation of models for continuous-flow cryogenic wind tunnels.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

196. *Cadwell, J. D.: **Model Design and Instrumentation for Intermittent Cryogenic Wind Tunnels.** Presented as Paper no. 10 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 8 pp., 2 refs.

N81-11058#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

The concept of a blowdown-to-atmosphere cryogenic wind tunnel was successfully proven when the Douglas Aircraft Company one-foot tunnel first operated cryogenically on May 20, 1977. Since that time a continuing effort has been underway at Douglas to develop the technology required to design, build, and instrument a model that can withstand the hostile environment of a cryogenic flow without sacrificing the acceptable accuracy that can be obtained at conventional temperatures, that is, 10 to 65 °C. This report summarizes the current state of this technology with a review of the many aspects of the design and instrumentation of a model for a blowdown-to-atmosphere cryogenic wind tunnel. Also included is a discussion of the model-conditioning required before a run to minimize the time for the model to stabilize at the adiabatic wall temperature, the model reheat system required after a run when model changes are to be made, and the humidity control of the test section and surrounding area to prevent frost from forming on the cold model.

*Douglas Aircraft Co., McDonnell Douglas Corp., 3855 Lakewood Blvd., Long Beach, CA 90846, U.S.A.

197. *Kilgore, R. A.: **Selection and Application of Instrumentation for Calibration and Control of a Continuous-Flow Cryogenic Tunnel.** Presented as Paper no. 11 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 10 pp., 7 refs.

N81-11059#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

This lecture describes those aspects of selection and use of calibration and control instrumentation that are influenced by the extremes in the temperature environment found in cryogenic tunnels. A description is given of the instrumentation and data acquisition system used in the NASA Langley 0.3-m Transonic Cryogenic Tunnel along with typical calibration data obtained in a 20- by 60-cm two-dimensional test section.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

198. *Cadwell, J. D.: **Calibration of a Blowdown-to-Atmosphere Cryogenic Wind Tunnel.** Presented as Paper no. 12 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 9 pp., 13 refs.

N81-11060#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

Calibration of short duration cryogenic wind tunnels pose difficulties and requirements beyond those already present in the calibration either of conventional short run time tunnels of or cryogenic continuous tunnels. The requirements and instrumentation for calibration of a transonic blowdown-to-atmosphere cryogenic wind tunnel are described, with emphasis on those aspects differing from the calibration of similar noncryogenic tunnels. Reference is made to the literature for detailed descriptions of conventional calibration practices which remain applicable for cryogenic blowdown tunnels.

*Douglas Aircraft Co., McDonnell Douglas Corp., 3855 Lakewood Blvd., Long Beach, CA 90846 U.S.A.

199. *Michel, R.: **The Development of a Cryogenic Wind-Tunnel Driven by Induction: Flow Control and Instrumentation Studies in a Pilot Facility at ONERA/CERT.** Presented as Paper no. 13 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 13 pp., 4 refs.

N81-11061#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

A new solution for an intermittent cryogenic wind tunnel, using high-pressure air as a driving gas and nitrogen as cooler, is being studied at the ONERA Toulouse Research Center. The contemplated application is the cryogenization of the transonic injector-driven tunnel T2, the project of which is presented in a second lecture (citation no. [205] in this bibliography). The experimental studies have been carried out until now on a pilot unit, a pressurized return circuit wind tunnel with a 10 × 10 cm test section which is about the 1/4th scale of T2. Systematic studies of the various problems related to the control and optimization of short cryogenic runs of an induction-driven tunnel as well as with experimental techniques, have been carried out and are summarized in this paper.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

200. *Kilgore, R. A.: **Experience in the Control of a Continuous Flow Cryogenic Tunnel.** Presented as Paper no. 14 in the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 15 pp., 7 refs.

N81-11062#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

The economical operation of liquid-nitrogen cooled cryogenic tunnels is critically dependent on fast and accurate control of the tunnel variables. In this lecture, the control problem of a continuous-flow fan-driven cryogenic tunnel is addressed, first by developing a lumped multivariable mathematical model of a tunnel and validating the model by reconciling the responses of the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) to the responses of the mathematical model on a simulator. Finally, the development of laws for the closed loop control of the tunnel pressure and temperature and the successful implementation of a control system for the 0.3-m TCT based on these laws are presented. We have achieved an accuracy of ±0.25 K in temperature and ±0.017 atm in pressure in the control of the 0.3-m TCT.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

201. *Cadwell, J. D.: **The Control of Pressure, Temperature and Mach Number in a Blowdown-to-Atmosphere Cryogenic Wind Tunnel.** Presented as Paper no. 15 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 8 pp., 1 ref.

N81-11063#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

The transonic section of the Douglas Aircraft Company 4-ft blowdown-to-atmosphere wind tunnel was placed in operation in March 1962. The tunnel control system that evolved and was in operation before the shutdown for modification is discussed as a starting point since one of the modification objectives is to be able to operate the tunnel in a conventional mode as well as at cryogenic temperatures. The modifications to the basic system to include the control of tunnel total temperature down to 100 K is described. The effects of the injection of large quantities of liquid nitrogen on the pressure control system are shown. The critical timing of the tunnel start considers the opening of the pressure control valve and the initiation of the liquid nitrogen into the airstream which can result in either a varying test section temperature distribution during a blow or reheating the precooled model. The evaluation of a shield to protect the precooled model during the tunnel start when the airstream is changing temperature from warm to the planned operating condition is presented.

*Douglas Aircraft Co., McDonnell Douglas Corp., 3855 Lakewood Blvd., Long Beach, CA 90846 U.S.A.

202. *Hartzuiker, J. P.; and *North, R. J.: **The European Transonic Windtunnel ETW.** Presented as Paper no. 16 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium, and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 17 pp., 6 refs.

N81-11064#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

This lecture summarizes the present situation concerning ETW: aerodynamics, performance, design, model handling, nitrogen systems, controls, and so forth. A short description is presented of the pilot tunnel, PETW, now under construction. Finally, the program on model design and instrumentation is described. Attention is paid especially to the cryogenic aspects of ETW.

*Technical Group ETW, c/o National Aerospace Laboratory, 1006 BM Amsterdam The Netherlands

203. *Igoe, W. B.: **Characteristics and Status of the U.S. National Transonic Facility.** Presented as Paper no. 17 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 11 pp., 25 refs.

N81-11065#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

The U.S. National Transonic Facility (NTF), a major use of the cryogenic wind-tunnel concept, is under construction at the NASA Langley Research Center and is scheduled to become operational in 1982. It will have a closed return fan-driven circuit with a 2.5-meter square slotted test section and will be pressurized up to 8.85 atm. It will provide chord Reynolds numbers of 120 million based on a chord of 0.25 m at transonic speeds using cold nitrogen as the test gas. This lecture gives many of the design features of the NTF and the status of its construction.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

204. *Cadwell, J. D.: **Progress Report on the Douglas Aircraft Company Four-Foot Cryogenic Wind Tunnel.** Presented as Paper no. 18 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 7 pp.

N81-11066#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

The McDonnell Douglas Corporation approved the modification of the existing Douglas Aircraft Company 4-ft trisonic wind tunnel to a cryogenic facility in mid 1976. The successful operation of the 1-ft pilot tunnel in May 1977 gave the final technical approval to proceed with the 4-ft tunnel modification program. This lecture gives an update on the progress of the modification. In addition, it presents a review of the test technique development program that will provide the technology necessary for the production type testing required for the design of new or derivative type aircraft programs.

*Douglas Aircraft Co., McDonnell Douglas Corp., 3855 Lakewood Blvd., Long Beach, CA 90846 U.S.A.

205. *Michel, R.: **A Cryogenic Transonic Intermittent Tunnel Project: The Induced-Flow Cryogenic Wind Tunnel T2 at ONERA/CERT.** Presented as Paper no. 19 at the AGARD/VKI Lecture Series 111, May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va., 9 pp., 1 ref.

N81-11067#

Note: For the compilation of papers of this Lecture Series see citation no. [217] in this bibliography.

This lecture presents the project for a new cryogenic intermittent tunnel, the induction-driven tunnel T2 at ONERA/CERT, which uses high-pressure air as a driving gas and liquid nitrogen as a cooler. A description of its main characteristics at ambient temperature operation is given at first. Then the various aspects of its transformation for a low-temperature operation are analyzed: modifications of the circuit, thermal insulation technique, liquid nitrogen injection, regulation systems, cryogenic operating mode, and expected performances.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

206. *Tobler, R. L.: **Materials for Cryogenic Wind Tunnel Testing.** NASA CR-164556, Rept. no. NBSIR 79-1624, May 1980, 135 pp., 325 refs.

N81-27120#

We have made a study to guide the evaluation and selection of materials and techniques to be used in construction of model aircraft for cryogenic wind-tunnel testing. In this report, the mechanical, thermal, and electrical property behavior of materials at temperatures as low as 77 K is briefly reviewed. Metals, structural alloys, nonmetals, composites, joining methods, coatings, sealants, adhesives, contact agents, lubricants, transducers, and instrumentation for cryogenic applications are discussed. Acceptable structural materials, conductors, and insulators are discussed for service at temperatures in the range 367 to 77 K. Numerous references to handbooks and other cryogenic data sources are cited as a guide to additional information.

*National Bureau of Standards, Boulder Laboratories, Boulder, CO 80302 U.S.A.
Contract: NASA Order L-59674-A

207. *Wegener, P. P.: **Study of Experiments on Condensation of Nitrogen by Homogeneous Nucleation at States Modelling Those of the National Transonic Facility.** Final Report. NASA CR-163217, May 1980, 58 pp., 12 refs.

N80-25294#

A cryogenic wind tunnel is based on the twofold idea of lowering drive power and increasing Reynolds number by operating with gaseous nitrogen near its boiling point. There are two possible types of condensation problems involved in this mode of wind-tunnel operation. They concern the expansion from the nozzle supply to the test section at relatively low cooling rates, and secondly the expansion around models in the test section. This secondary expansion involves higher cooling rates and shorter time scales. In addition to these two condensation problems, it is not certain what purity of nitrogen can be achieved in a large facility. Therefore, one cannot rule out condensation processes other than these of homogeneous nucleation.

*Yale University, Department of Engineering and Science, 206 Elm Ave., New Haven, CT 06520 U.S.A.
NASA Grant NSG-1612

208. *Ladson, C. L.; and *Kilgore, R. A.: **Instrumentation for Calibration and Control of a Continuous-Flow Cryogenic Tunnel.** NASA TM-81825, May 1980, 11 pp., 7 refs. This paper is based on one presented at the AGARD/VKI Lecture Series 111 on Cryogenic Wind Tunnels, May 1980.

N80-24265#

This paper describes those aspects of selection and use of calibration and control instrumentation that are influenced by the extremes in the temperature environment to be found in cryogenic tunnels. A description is given of the instrumentation and data acquisition system used in the NASA Langley 0.3-m Transonic Cryogenic Tunnel along with typical calibration data obtained in a 20- by 60-cm two-dimensional test section.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

209. *Ferris, A. T.: **Force Instrumentation for Cryogenic Wind Tunnels Using One-Piece Strain-Gage Balances.** NASA TM-81845, June 1980, 17 pp. (This paper is based on one presented at the NASA Cryogenic Technology Conference held at NASA Langley Research Center, November 27-29, 1979.)

N81-17406#

The use of cryogenic temperatures in wind tunnels to achieve high Reynolds numbers has imposed a harsh operating environment on the force balance. We have made laboratory tests to study the effect cryogenic temperatures have on balance materials, gages, wiring, solder, adhesives, and moisture proofing. We have made wind-tunnel tests using a one-piece three-component balance to verify laboratory results. These initial studies indicated we can obtain satisfactory force data under steady-state conditions.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

210. *Balakrishna, S.: **Minimum Energy Test Direction Design in the Control of Cryogenic Wind Tunnels.** Progress Rept.

period ending June 1980. NASA CR-163244, June 1980, 56 pp., 6 refs.

N81-11457#

This report details the test direction planning problems associated with cryogenic wind tunnels, analyzed as a part of the project *Modeling and Control of Transonic Cryogenic Tunnels*, sponsored by NASA Langley Research Center. The report is concerned with realizing desired flow Reynolds number-Mach number combinations at which data is sought, with minimum liquid nitrogen consumption. The contents of this document complement the reports on modeling phase activity in citation no. [168] and the control analysis phase activity in citation no. [182] of this bibliography.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.
NASA Grant NSG-1503

211. *Hanson, P. W.: **An Assessment of the Future Roles of the National Transonic Facility and the Langley Transonic Dynamics Tunnel in Aeroelastic and Unsteady Aerodynamic Testing.** NASA TM-81839, June 1980, 52 pp., 16 refs.

N80-28377#

This paper discusses the characteristics and capabilities of the two tunnels that relate to studies in the fields of aeroelasticity and unsteady aerodynamics. Scaling considerations for aeroelasticity and unsteady aerodynamics testing in the two tunnels are reviewed. Some of the special features (or lack thereof) of the NASA Langley Research Center Transonic Dynamics Tunnel (TDT) and the U.S. National Transonic Facility (NTF) that will weigh heavily in any decisions of making a given study in the two tunnels are discussed. For illustrative purposes a fighter and a transport airplane are scaled for tests in the NTF and in the TDT, and the resulting model characteristics are compared. The NTF is designed specifically to meet the need for higher-Reynolds-number capability for flow simulation in aerodynamic performance testing. However, the NTF can be a valuable tool for evaluating the severity of Reynolds number effects in the areas of dynamic aeroelasticity and unsteady aerodynamics. On the other hand, the TDT was built specifically for studies and tests in the field of aeroelasticity. Except for tests requiring the Reynolds-number capability of the NTF, the TDT will remain the primary tunnel for tests of dynamic aeroelasticity and unsteady aerodynamics.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

212. *Bursik, J. W.; and **Hall, R. M.: **Effects of Various Assumptions on the Calculated Liquid Fraction in Isentropic Saturated Equilibrium Expansions.** NASA TP-1682, June 1980, 33 pp., 3 refs.

N80-25615#

The saturated equilibrium expansion approximation for two-phase flow often involves ideal-gas and latent-heat assumptions to simplify the solution procedure. This approach is well documented by Wegener and Mack and works best at low pressures where deviations from ideal-gas behavior are small. In this paper we use a thermodynamic expression for liquid mass fraction that is decoupled from the equations of fluid mechanics to compare the effects of the various assumptions on nitrogen-gas saturated equilibrium expansion flow starting at 8.81 atm, 2.99 atm, and 0.45 atm, which are conditions representative of transonic cryogenic wind tunnels. For the highest-pressure case, the entire set of ideal-gas and latent-heat assumptions are shown to be in error by 62 percent for the value of heat capacity and latent heat used in this paper. An approximation of the exact, real-gas expression is also developed using a constant, two-phase isentropic expansion coefficient which results in an error of only 2 percent for the high-pressure case.

*Rensselaer Polytechnic Institute, Troy, NY 12181 U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

213. *Faulmann, D.: **Cryogenic Wind Tunnels: Problems of Continuous Operation at Low Temperatures.** (Souffleries Cryogeniques Problemses Lies au Fonctionnement Continue en Basse Temperature) Rep. OA9/5007-AYD, DERAT-9/5007/DY, ONERA, Toulouse, France, June 1980, 46 pp., 7 refs., in French.

Note: For an English translation of this report and an abstract see citation no. [462] in this bibliography.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

214. *Fancher, M. F.: **Hot-film Anemometry for Boundary Layer Transition Detection in Cryogenic Tunnels.** European Mechanical Colloquium, Euromech 132, held at the Ecole Centrale de Lyon, Rhone, France, July 2-4, 1980, 16 pp.

NASA Langley Technical Library Number CN-153,419

This paper gives detailed information on boundary-layer transition and separation. About 100 sensors were located on an aerofoil by a thin plastic film (Kapton or Mylar). Experiments were run in a cryogenic tunnel. The important question of the heat loss to the substrate did not seem, however, to have been examined. For this particular problem, a useful reference is Brison, Charnay & Comte-Bellot (1979).

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Note: This paper does not appear in Euromech 132, even though it was presented. Contact author or NASA Langley Technical Library for copies.

215. *Dueker, M.; and *Koppenwallner, G.: **Comparisons Between Experimental Observations and Predictions Obtained With Classical Homogeneous Nucleation Theory for Nitrogen Condensation in Large Freejet Experiments.** Presented as Paper no. 172 at the 12th International Symposium on Rarefied Gas Dynamics, Charlottesville, Va., July 7-12, 1980. In vol. 74, "Progress in Astronautics and Aeronautics," pp. 1190-1210, 13 refs.

N82-13072#

Classical condensation theory is tested for its ability to predict condensation onset and the ensuing droplet growth process in freejet expansions of nitrogen. A computer program combining nucleation theory, a droplet growth model, and the gas dynamics of freejet flow is used for this purpose. Comparisons of the theoretical results with experiments, covering a large range of expansion isentropes, reveal generally unsatisfactory results. Of various correction schemes tested, a particular surface tension assumption for the solid clusters gave at least approximate agreement with measured data.

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216. *Johnson, C. B.: **Theoretical Study of Nonadiabatic Boundary-Layer Stabilization Times in a Cryogenic Wind Tunnel for Typical Stainless Steel Wing and Fuselage Models.** NASA TM-80212, July 1980, 43 pp., 9 refs.

N80-25614#

The time varying effect of nonadiabatic wall conditions on boundary-layer properties was studied for a two-dimensional wing section and an axisymmetric fuselage. The wing and fuselage sections are representative of the wing root chord and fuselage of a typical transport model for the U.S. National Transonic Facility. The analysis was made with a solid wing and three fuselage configurations (one solid and two hollow with varying skin thicknesses) all made from AISI type 301S stainless steel. The displacement thickness and local skin friction were studied at a station on the model in terms of the time required for these two boundary layer properties to reach an adiabatic wall condition after a 50 K step change in total temperature. The analysis was made for a free stream Mach number of 0.85, a total temperature of 117 K, and stagnation pressures of 2, 6, and 9 atm.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

217. *Goodyer, M. J. (Lecture Series Director): **Cryogenic Wind Tunnels; AGARD/VKI Lecture Series 111,** July 1980, 271 pp. Held May 19-23, 1980 at Rhode Saint Genèse, Belgium and May 27-30, 1980 at NASA Langley Research Center, Hampton, Va.

N81-11048#

Note: The Series was sponsored by the Fluid Dynamics Panel of AGARD and implemented by the von Karman Institute. (Nineteen papers were presented and are included as citation nos. [187 through 205] in this bibliography

This Lecture Series is designed for engineers, including those experienced with conventional wind tunnels, wishing to acquire in a concentrated form the principles and practice of cryogenic wind tunnels. The emphasis is on the unfamiliar facets of technology which must be applied, and on solutions to special problems which arise from the exploitation of a low-temperature test gas. Lectures provide up-to-date information on the aerodynamic and mechanical design of continuous and intermittent cryogenic wind tunnels and their models, and on techniques for controlling test parameters. Design information includes properties of materials, the storage and handling of cryogenic liquids, insulation systems for pipelines and tunnel circuits, and safety requirements. Solutions are included for the special requirements of instrumentation systems for plant, tunnel, and model. The physical processes are described which determine the lower limits of operating temperature. The four major cryogenic wind-tunnel projects for aeronautical testing are also described; two of these being in the U.S.A. and two in Europe.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

218. *Mohan, S. R.; and *Stollery, J. L.: **A Study of the Temperatures Achievable by Expansion of High Pressure Gas.** The Aeronautical Journal, vol. 84, August 1980, pp. 253-255, 7 refs.

A81-27896

An experimental study of the achievement of cryogenic temperatures by the adiabatic isentropic expansion of a gas is presented. The test apparatus is a light-piston tunnel, and the working gas is nitrogen. It was determined cryogenic temperatures were achieved by a polytropic process with an exponent of between 1.3 and 1.4. To achieve a temperature of 120 K from an initial temperature of 300 K, a pressure ratio of 35 will typically be required.

*Cranfield Institute of Technology, Cranfield, Beds MK43 0AL, England

219. *Balakrishna, S.: **Effects of Boundary-Layer Treatment on Cryogenic Wind-Tunnel Controls.** Progress Report, period ending August 1980, NASA CR-159372, August 1980, 62 pp., 5 refs.

N81-12120#

This report analyzes the manner in which various possible schemes for sidewall boundary-layer treatment that can be used to achieve a two-dimensional flow field around the model in the NASA Langley 0.3-m Transonic Cryogenic Tunnel affect the basic tunnel controls. This work constitutes a part of the project *Modeling and Control of Transonic Cryogenic Tunnels* sponsored by NASA Langley Research Center. The contents of this document complement other reports of the project. (Check the author index for other reports by this author.)

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.

220. *Dinguirard, M.; *Serrot, G.; *Duffaut, J.; *Blanchard, A.; *Dor, J.-B.; and *Breil, J. F.: **Qualitative Study of the Appearance of Nitrogen Fog in the T'2 Cryogenic Induction Wind Tunnel.** English translation of "Etude qualitative de l'apparition du broulillard d'azote dans la soufflerie cryogenique a induction T'2," ONERA/CERT Rep. 1/6059, February 1980, 73 pp. Translated into English by Kanner (Leo) Associates, Redwood City, Calif. NASA TM-75857, August 1980, 64 pp., 5 refs.

N81-19138#

Note: For the French version of this report see citation no. [176] in this bibliography.

The T'2 cryogenic wind-tunnel operation is described. The liquid nitrogen injection system is presented in detail. This system injects the nitrogen in a high-speed finely-atomized form into the air stream. To show the effect of the use of this system a first set of tests was run and the results analyzed. Estimates were made of the concentration of particles in the test area as a function of pressure, temperature, and Mach number. These results are not easily interpreted; nevertheless, certain general conclusions can be reached. This mainly qualitative preliminary study shows a significant number of particles were observed in the discharge when its temperature was below the normal range of temperatures in T'2, (130 to 140 K).

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221. *Thibodeaux, J. J.; and **Balakrishna, S.: **Development and Validation of a Hybrid-Computer Simulator for a Transonic Cryogenic Wind Tunnel.** NASA TP-1695, September 1980, 84 pp., 4 refs.

N80-31413#

A study was made to model the cryogenic wind-tunnel process, to validate the model by the use of experimental data from the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT), and to construct an interactive simulator of the cryogenic tunnel using the validated model. Additionally, this model has been used for designing closed-loop feedback control laws for regulation of temperature and pressure in the 0.3-m TCT. The global mathematical model of the cryogenic tunnel that has been developed consists of coupled, nonlinear differential governing equations based on an energy-state concept of the physical cryogenic phenomena. Process equations and comparisons between actual tunnel responses and computer-simulation predictions are given. Also included are the control laws and simulator responses obtained by using the feedback schemes for closed-loop control of temperature and pressure.

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**Old Dominion University, Norfolk, VA 23508-0369 U.S.A.

222. *Gloss, B. B.: **Some Aerodynamic Considerations Related to Wind Tunnel Model Surface Definition**. NASA TM-81820, September 1980, 13 pp., 9 refs.

N80-32376#

Note: For an earlier presentation of this paper and an abstract see citation no. [162] in this bibliography.

The aerodynamic considerations related to model surface definition are examined with particular emphasis in areas of fabrication tolerances, model surface finish, and orifice-induced pressure errors. The effect of model surface roughness texture on skin friction is also discussed.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

223. *Buckley, J. D.; and *Sandefur, P. G., Jr.: **Low-Temperature Solder for Joining Large Cryogenic Structures**. NASA TM-81836, September 1980, 15 pp., 5 refs.

N80-32490#

Three joining methods were considered for use in making cooling coils for the U.S. National Transonic Facility. After analysis and preliminary testing, soldering was chosen as the cooling coil joining technique over mechanical force fit and brazing techniques. Charpy V-Notch tests, cyclic thermal tests (ambient to 77.8 K), and tensile tests at cryogenic temperatures were made on solder joints to evaluate their structural integrity. It was determined low-temperature solder can be used to ensure good fin-to-tube contact for cooling-coil applications.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

224. *Maurer, F.: **Project European Transonic Windtunnel. (Projekt Europaischer Transschall-Windkanal).** Bundesministerium fur Forschung und Technologie, Statusseminar zur Luftfahrtforschung und Luftfahrt-technologie, 2nd, Garmisch Partenkirchen, Germany, October 8-9, 1980, Paper, 38 pp., 11 refs., in German.

A81-37640#

A status report concerning the European Transonic Windtunnel project is provided. The report describes the situation existing after the predesign phase and refers to the problem of the new discussion regarding the test-section cross section with respect to size and form. The organization of the project definition phase is based on a memorandum of understanding between Germany, France, Great Britain, and Holland. The project has been initiated because it was felt there was an urgent requirement for a high-Reynolds-number transonic wind tunnel in Europe. The requirement is to be satisfied by a pressurized continuous-flow tunnel using nitrogen as the test gas, and to be capable of being operated over a range of temperatures from ambient down to about 90 K.

*DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

225. *Howell, R. R.; and *Joplin, S. D.: **A System for Model Access in Tunnels With an Unbreathable Test Medium**. International Council of the Aeronautical Sciences, Proceedings, 12th Congress, Munich, Germany, (A81-11601), October 12-17, 1980, pp. 817-822, 7 refs.

A81-11672

In many specialty wind tunnels, test gases other than ambient air are used to meet special testing requirements. A typical example is the use of freon as the test gas to achieve a realistic density ratio between gas and model for studying flutter stability boundaries. Another example is the use of pressurized air to elevate the stream density and increase Reynolds number or dynamic pressure simulation. Such specialty tunnels require a system of access to the model which will allow services and changes to the model without exposing people to the unnatural and perhaps hostile environment or requiring the venting and purging of the entire tunnel circuit. This paper describes the plenum and model access systems for the forthcoming U.S. National Transonic Facility where gaseous nitrogen at temperatures between 338 and 78 K and at pressures to 9 bars will be used as the test gas. The operation at cold temperatures imposes some additional requirements which make the access systems more difficult to design and time consuming to operate than for conventional (ambient temperature) wind tunnels.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

226. *Balakrishna, S.: **Modeling and Control of Transonic Cryogenic Wind Tunnels**. Final Summary Report, Period ending October 1980. NASA CR-163588, October 1980, 53 pp., 7 refs.

N80-32403#
or
N81-12121#

This report summarizes the many faceted research activities of the project *Modeling and Control of Transonic Cryogenic Wind Tunnels*, sponsored by the NASA Langley Research Center. Reported are the model synthesis activity, control analysis activity, test direction design analysis, and effects of boundary-layer treatment on cryotunnel controls. The activities in each of these areas are briefly reviewed, and they are complemented by recommendations for improving some of the engineering systems of the 0.3-m Transonic Cryogenic Tunnel (TCT) to which the bulk of the research was oriented.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.
NASA Grant NSG-1503

227. *Blanchard, A.; *Dor, J.-B.; and *Breil, J. F.: **Measurements of Temperature and Pressure Fluctuations in the T'2 Cryogenic Wind Tunnel**. NASA TM-75408, October 1980, 48 pp., 9 refs. Transl. by Kanner (Leo) Associates, Redwood City, Calif. of "Mesures des Fluctuations de Temperature et de Pression dans la Soufflerie Cryogenique T'2" (Toulouse). OA8/5007 and

DERAT no. 8.5007 DN January 1980, 22 pp., 9 refs., includes 19 figs.

N81-26158#

Note: For the original French report see citation no. [175] in this bibliography.

Cold wire measurements of temperature fluctuations were made in the DERAT T'2 induction-powered cryogenic wind tunnel for 2 types of liquid nitrogen injectors. Thermal turbulence measured in the settling chamber depends to a great extent on the injector used; for fine spray of nitrogen drops, this level of turbulence seemed completely acceptable. Fluctuations in static pressure taken from the walls of the test section by Kulite sensors showed there was no increase in aerodynamic noise during cryogenic operation.

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NASA Contract NASw-3199 (for translation)

228. *Lawing, P. L.; *Sandefur, P. G., Jr.; and *Wood, W. H.: **A Construction Technique for Wind-Tunnel Models.** NASA Tech. Brief LAR-12710, Fall 1980.

Miniature wind-tunnel models must satisfy stringent physical requirements, including high strength, good surface finish, and corrosion resistance. Some of the most troublesome problems result from the internal steel tubes that lead to small, pressure-sensing, surface orifices. These tubes may plug or leak, and the cavities they require weaken the model. Since the plumbing cannot be installed until late in the machining process, considerable fabrication time is wasted if defects arise at that point. These problems are overcome by machining the pressure channels as an integral part of the model. A method of accomplishing this is described. In addition to solving construction problems for wind-tunnel models, this technique should be useful in fuel injection, transpiration cooling, and similar applications involving small elements of fluid flow. Since the technique has been developed for 17-4 PH alloy stainless steel, it can be used for corrosive or high-temperature environments.

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For further information, contact the Technology Utilization Officer, M.S. 139A, at NASA Langley Research Center and refer to LAR-12710

229. *Blanchard, A.; *Dor, J.-B.; *Mignosi, A.; and *Breil, J. F.: **Research on an Induction Driven Cryogenic Wind Tunnel.** (Recherches sur une Soufflerie Cryogénique Fonctionnant par Induction). Paper AAAF NT 80-32 at 17th AAAF Colloque d'Aerodynamique Appliquee, Grenoble, France, November 12-14, 1980, 42 pp., 6 refs., in French.

A81-33935#

A new solution to the problem of flight-test and wind-tunnel-test similitude in transonic wind tunnels is to increase the Reynolds number of the transonic wind tunnels by operating at low temperature. This solution chosen for the European transonic wind tunnel has been studied for a few years at the Toulouse Research Center of ONERA, on a small circuit T'2, which is 1/4th scale model of the induction-driven tunnel T2. The circuit in the present configuration and its typical cryogenic runs are briefly presented, then the main results about the flow qualities obtained in T'2 are given. Research has been oriented more especially toward the transformation of the T2 tunnel. The studies involve essentially the choice of the internal insulation and the definition of the liquid nitrogen injection device.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

230. *Mignosi, A.; *Faulmann, D.; and *Seraudie, A.: **Induction Driven Transonic Wind Tunnel T2: Operation at Room Temperature and Cryogenic Adaptation.** Association Aeronautique et Astronautique de France, 17th Colloque d'Aerodynamique Appliquee, Grenoble, France, November 12-14, 1980. Rept. ONERA TP 1980-142, 1980, 36 pp., in French. Translation into English of LaRecherche Aerospatiale, Bulletin Bimestriel no. 1981-3, May-June 1981, pp. 203-215. Rep. no. ESA-TT-714, pp. 63-74, 9 refs.

A81-21916# (in French)
N82-19158# (in English)

The transformation of the induction-driven wind-tunnel T2 (0.4 × 0.4 m) into a cryogenic intermittent wind tunnel which uses high-pressure air as driving gas and nitrogen as coolant is described. The operating mode and optimization of the wind tunnel for low-temperature operation are discussed. Theoretical and experimental aspects of the transformed tunnel; i.e., modification of the circuit, thermal insulation techniques, liquid nitrogen injection, start-up process, cryogenic operating mode, and expected performance, are presented.

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231. *Maurer, F.; *Viehweger, G.; and *Lorenz-Meyer, W.: **Developments in the Area of Cryo-Wind Tunnel Technology by the DFVLR** (Deutsche Forschungs-und Versuch-sanstalt für Luft- und Raumfahrt). DFVLR-Nachrichten, no. 31, November 1980, pp. 8-12, in German.

A81-15702

Note: For English translation see citation no. [242] in this bibliography.

Research is described of new wind-tunnel assemblies which, in contrast to present facilities, simulate free-flight conditions. In addition to Mach number, the Reynolds number is taken into consideration for similitude of friction level and flow separation. The German-Dutch subsonic wind tunnel (DNW) approaches the desired results, though the drive power increases not only with the second power of the size but increases with the third power of the speed.

*DFVLR–Porz-Wahn, Postfach 90 60 58, D-5000 Köln 90 Porz-Wahn, FRG

232. *Lawing, P. L.; *Adcock, J. B.; and *Ladson, C. L.: **A Fan Pressure Ratio Correlation in Terms of Mach Number and Reynolds Number for the Langley 0.3-Meter Transonic Cryogenic Tunnel.** NASA TP-1752, November 1980, 18 pp., 10 refs.

N81-10005#

Calibration data for the two-dimensional test section of the NASA Langley 0.3-meter Transonic Cryogenic Tunnel are used to develop a Mach number-Reynolds number correlation for the fan-pressure ratio in terms of test-section conditions. It is shown that well-established engineering relationships can be combined to form an equation which is functionally analogous to the correlation. Additionally, a geometric loss coefficient which is independent of Reynolds number or Mach number can be determined. Present and anticipated uses of this concept include improvement of tunnel control schemes, comparison of efficiencies of operationally similar wind tunnels, prediction of tunnel test conditions and associated energy usage, and determination of Reynolds number scaling laws for similar fluid flow systems.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

233. *Young, C. P., Jr.: **Pathfinder Model Program for the National Transonic Facility**. High Reynolds Number Research–1980, paper no. 5, NASA CP-2183 (N81-31130), pp. 37-52. (Comments on pp. 291-292.) (Presented December 1980.)

N81-31135#

An overview of the Pathfinder Model Program is presented in this paper. The Pathfinder program is a major research and development activity that is underway in support of the U.S. National Transonic Facility Activation Plan. The program scope, models design approach, and Pathfinder model configurations are presented along with a discussion of major supportive program activities. In addition, the anticipated design criteria for NTF models are presented.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

234. *Lawing, P. L.; and *Kilgore, R. A.: **Model Experience in the Langley 0.3-m Transonic Cryogenic Tunnel**. High Reynolds Number Research–1980, paper no. 6, NASA CP-2183 (N81-31130), pp. 53-74. (Comments on p. 292.) (Presented December 1980.)

N81-31136#

The development of wind tunnels that can be operated at cryogenic temperatures has placed several new demands on our ability to build and instrument wind-tunnel models. This paper presents a brief summary of the model building, development, and testing experience gained during 8 years of operation of the NASA Langley 0.3-m Transonic Cryogenic Tunnel.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

235. *Guarino, J. F.: **Instrumentation Systems for the National Transonic Facility**. High Reynolds Number Research–1980, paper no. 7, NASA CP-2183 (N81-31130), pp. 75-80. (Comments on p. 294.) (Presented December 1980.)

N81-31137#

Instrumentation and measurement systems are important elements in any complex research facility. The U.S. National Transonic Facility, with its unique operational characteristics, is clearly a complex facility and as such, represents a significant challenge to wind-tunnel instrument designers. This paper briefly describes the instrument requirements imposed by the new testing environment, the instrument systems being provided for facility calibration and operation, and the research and development activities directed at meeting overall instrument and measurement requirements.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

236. *Ladson, C. L.; and *Kilgore, R. A.: **Instrumentation for Calibration and Control of a Continuous-Flow Cryogenic Tunnel**. High Reynolds Number Research–1980, paper no. 8, NASA CP-2183, (N81-31130), pp. 81-92. (Comments on p. 295.) (Presented December 1980.)

N81-31138#

This paper describes those aspects of selection and application of calibration and control instrumentation that are influenced by the extremes in the temperature environment to be found in cryogenic tunnels. A description is given of the instrumentation and data acquisition system used in the NASA Langley 0.3-m Transonic Cryogenic Tunnel along with typical calibration data obtained in a 20- by 60-cm two-dimensional test section.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

237. *Hall, R. M.: **Onset of Condensation Effects in Cryogenic Wind Tunnels**. High Reynolds Number Research-1980, paper no. 9, NASA CP-2183 (N81-31130), September 1981, pp. 93-104. (Comments on pp. 295-296.) (Presented December 1980.)

N81-31139#

The onset of condensation effects in cryogenic wind tunnels limits their minimum operating temperatures. If this onset of effects occurs below saturation temperature, the tunnels may be operated at the lower temperatures and additional benefits to cryogenic tunnel operation, such as increased Reynolds number capability and reduced operating costs, will result. Both homogeneous and heterogeneous nucleation processes are discussed as they pertain to continuous-flow cryogenic wind tunnels. Examples from condensation experiments in the NASA Langley 0.3-m Transonic Cryogenic Tunnel are also reviewed.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

238. *Stainback, P. C.; and *Fuller, D. E.: **Flow Quality Measurements in Transonic Wind Tunnels and Planned Calibration of the National Transonic Facility**. High Reynolds Number Research-1980, paper no. 10, NASA CP-2183, (N81-31130), September 1981, pp. 105-122. (Comments on pp. 297-300.) (Presented December 1980.)

N81-31140#

The need for mean flow and dynamic flow-quality measurements was considered for the U.S. National Transonic Facility (NTF). Past experience in making flow-quality measurements in transonic flows and at cryogenic temperatures was used to guide the selection of methods to be used in the NTF. It appears suitable instrumentation will be available and adequate experience has been obtained to insure that the proper calibration of the NTF can be made.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

239. *Kempka, S. N.; and *Clausing, A. M.: **The Influences of Variable Properties on Natural Convection From Vertical**

Surfaces. University of Illinois Technical Rept. ME-TN-81-9180-2, Vol. II of Final Rept., January 1981, 59 pp.

N82-77735

A central receiver atop a tower absorbs solar energy reflected to it from a surrounding array of heliostats. The thermal losses from the receiver are an unknown factor. Fundamental research in convective heat transfer is required to obtain data necessary for accurate prediction of thermal losses. One method of obtaining combined convection data is cryogenic modeling. Low-temperature experiments in the UIUC Cryogenic Heat Transfer Facility agree well with existing correlations. A description of the apparatus is given.

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Basic Research Sponsored by Sandia Nat. Labs.
Research Grant no. 87-9180

240. *Ferris, A. T.; and *Moore, T. C.: **Force Instrumentation for Cryogenic Wind Tunnels**. Presented at the 27th International Instrumentation Symposium, Indianapolis, Ind., April 27-30, 1981, pp. 149-160.

A82-41783

One-piece multicomponent strain-gage force transducers have been used successfully to measure aerodynamic loads in wind-tunnel models for many years. These transducers are designed to operate in temperatures ranging from 295 to 355 K. A new wind tunnel under construction at NASA Langley Research Center in Hampton, Virginia, will obtain more accurate data in aircraft research by simulating full-scale Reynolds numbers. This tunnel will have the capability of wind-tunnel model testing at cryogenic temperatures (down to 77 K) and high pressure (up to 9 atm). An extensive testing program, including cryogenic wind-tunnel tests, has determined materials and techniques usable to obtain accurate force measurements at these very low temperatures. This paper presents the effect of the cryogenic environment on the transducer material and on the transducer's electrical components, the gaging techniques developed to eliminate undesirable effects, and the results of wind-tunnel verification tests.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

241. *Gartrell, L. R.; *Gooderum, P. B.; *Hunter, W. W., Jr.; and *Meyers, J. F.: **Laser Velocimetry Technique Applied to the Langley 0.3-Meter Transonic Cryogenic Tunnel**. NASA TM-81913, April 1981, 35 pp., 6 refs.

N81-22331#

A low-power (15 mW) laser velocimeter operating in the forward-scatter mode was used to measure free-stream mean velocities in the NASA Langley 0.3-m Transonic Cryogenic Tunnel. Velocity ranging from 51 to 235 m/s was measured with at least ~1-percent accuracy. These measurements were obtained for a variety of nominal tunnel conditions: mach numbers from 0.20 to 0.77, total temperatures from 100 to 250 K, and pressures from 101 to 152 kPa (1.0 to 1.5 atm). Particles were not injected to augment the existing Mie scattering material. It is postulated the existing light scattering material in these tests was liquid nitrogen droplets normally injected to control the tunnel temperature. Signal levels during the tests indicated that the average particulate diameter was greater than 1.0 m. Tunnel vibrations and thermal effects, considered to be potential problems before the tests, had no detrimental effects on the optical system.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

242. *Maurer, F.; *Viehweger, G.; and *Lorenz-Meyer, W.: **Development in the Area of Cryo-Wind Tunnel Technology**. NASA TM-75475, April 1981, 16 pp. Translation of "Arbeiten der DFVLR auf dem Geibiet der Kryo-Windkanaltechnik," DFVLR-Nachrichten, no. 31, November 1980, pp. 8-12.

X81-10220

Note: For the original German form and an abstract see citation no. [231] in this bibliography.

Translation by Scientific Translation Service, Santa Barbara, CA.

*DFVLR-Porz-Wahn, Postfach 90 60 58, D-5000 Köln 90 Porz-Wahn, FRG
NASA Contract NASw-3198

243. *Schroeder, W.: **European Transonic Wind Tunnel ETW-Status of the Project at the End of the Predesign Phase**. Presented at Aachen, Germany, May 11-14, 1981, 27 pp., 24 refs., in German.

DGLR Paper 81-027 A81-47563#

The predesign of the basic European Transonic Windtunnel (ETW) with a test cross-section area of 3.2 m^2 and a maximum pressure of 4.5 bar was completed in spring 1980. The need for a European transonic wind tunnel for tests at high Reynolds numbers is discussed, taking into account current wind-tunnel developments in Europe and the U.S. The specifications for the ETW are considered. The maximum Reynolds number for the ETW has been raised to a value of 50 million. This was done to enhance the cost effectiveness of testing in the ETW and to reduce development risks. The ETW will, therefore, provide for future European aircraft development conditions for full-scale testing over a wide flight range. Attention is given to the performance spectrum of the ETW, an evaluation of the predesign, operational aspects of the ETW, the thermal inertia of the model, the pilot wind tunnel, the cryogenic technology program, and the future phases of the ETW program.

*DGLR-Godesberger Allee 70, Postfach 260109, D-5300 Bonn 2 Godesberger Allee 70, FRG

244. *Johnson, C. B.; and *Adcock, J. B.: **Measurement of Recovery Temperature on an Airfoil in the Langley 0.3-m Transonic Cryogenic Tunnel**. Presented at the AIAA 16th Thermophysics Conference, Palo Alto, Calif., June 23-25, 1981, 10 pp., 14 refs.

AIAA-81-1062 A81-39074#

Measurements were made at Mach numbers of 0.60 and 0.84 over a Reynolds number per meter range from about 15 million to about 335 million. The measured recovery temperatures were considerably below those associated with ideal-gas ambient temperature wind tunnels. This difference was accentuated as the stagnation pressure increased and the total temperature decreased. A boundary-layer code modified for use with cryogenic nitrogen adequately predicted the measured adiabatic wall temperature at all conditions. A quantitative on-line assessment of the nonadiabatic condition of a model can be made during the operation of a cryogenic wind tunnel by using a correlation for the adiabatic wall temperature which is only a function of total temperature, total pressure, and local Mach number on the model.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

245. *Wigley, D. A.: **The Structure and Properties of Diffusion Assisted Bonded Joints in 17-4 PH, Type 347, 15-5 PH and Nitronic 40 Stainless Steels**. NASA CR-165745, July 1981, 30 pp.

N81-30251#

Initial trials at NASA Langley Research Center have demonstrated that diffusion assisted bonds can be formed in 17-4 PH, 15-5 PH, type 347 and Nitronic 40 stainless steels using electrodeposited copper as the bonding agent. The bonds are analyzed by conventional metallographic, electron microprobe analysis, and scanning electron microscopic techniques as well as Charpy V-Notch impact tests at temperatures of 77 and 300 K. The results are discussed in terms of a postulated model for the bonding process.

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Contract NAS1-16000 (Research supported by Kentron International, Inc., Univ. of Southampton, and NASA.)

246. *Boyden, R. P.; and *Johnson, W. G., Jr.: **Preliminary Results of Buffet Tests in a Cryogenic Wind Tunnel**. NASA TM-81923, July 1981, 37 pp., 9 refs.

N81-31124#

Buffet tests of two wings with different leading-edge sweep have shown it is feasible to use the standard wing root bending moment technique in a cryogenic wind tunnel. The results for the 65° delta wing show the importance of matching the reduced frequency parameter in model tests for planforms sensitive to reduced frequency parameter if quantitative buffet measurements are required. The unique ability of a pressurized cryogenic wind tunnel to separate the effects of Reynolds number and aeroelastic distortion by variations in the tunnel stagnation temperature and pressure was demonstrated.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

247. *Fuller, D. E.: **Guide for Users of the National Transonic Facility**. NASA TM-83124, July 1981, 41 pp., 5 refs. Includes Appendix B, pp. 23-35, by Gloss, B. B. and Nystrom, D.

N81-29139#

The U.S. National Transonic Facility (NTF) is a fan-driven, closed-circuit, continuous-flow, pressurized wind tunnel. The test section is 2.5 × 2.5 m and 7.62 m long with a slotted-wall configuration. The NTF will have a Mach number range from 0.2 to 1.2, with Reynolds numbers up to 120 million at Mach 1 (based on a reference length of 0.25 m). The pressure range will be from 1 to about 9 bars (1 bar = 100 kPa), and the temperature can be varied from 340 to 78 K. This report provides potential users of the NTF with the information required for preliminary planning of test programs and for preliminary layout of models and model supports which may be used in such programs. Appendix B (by Blair B. Gloss and Donna Nystrom) presents estimated performance maps for the NTF.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

248. *Blanchard, A.; *Delcourt, V.; and *Plazanet, M.: **Problems Associated With Operations and Measurement in Cryogenic Wind Tunnels**. "Problemes Lies au Fonctionnement et aux Mesures en Soufflerie Cryogenique," Rep. OA-13/5007-AYD DERAT-13/5007-DY, July 1981, 61 pp., 6 refs., in French.

Note: For an English translation and an abstract see citation no. [463] in this bibliography.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

249. *Wigley, D. A.; **Sandefur, P. G., Jr.; and **Lawing, P. L.: **Preliminary Results on the Development of Vacuum Brazed Joints for Cryogenic Wind Tunnel Aerofoil Models**. Advances in Cryogenic Engineering (Materials), vol. 28, August 10-14, 1981, pp. 893-903, 6 refs.

A81-44667#

The results of these initial experiments show high-strength void-free bonds can be formed by vacuum brazing of stainless steels using copper and nickel-based filler metals. In Nitronic 40, brazed joints have been formed with strengths in excess of the yield strength of the parent metal and even at liquid nitrogen temperatures the excellent mechanical properties of the parent metal are only slightly degraded. The poor toughness of 15-5 PH stainless steel at cryogenic temperatures is lowered even further by the presence of the brazed bonds investigated. It is highly unlikely the technique would be used for any critical areas of aerofoil models intended for low-temperature service. Nevertheless, the potential advantages of this simplified method of construction still have attractions for use at ambient temperatures.

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**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
Contract NAS1-16000 (Research Supported by Kentron International, Inc., Univ. of Southampton, and NASA.)

250. *Clausing, A. M.: **An Experimental Investigation of Convective Losses From Solar Receivers, Final Rept**. Volume I, Executive Summary. University of Illinois TR-ME-TN-81-9180-3, August 1981, 25 pp., 18 refs.

N83-10500#

The cryogenic test facility is described. A cryogenic environment provides a means to obtain simultaneously, large increases in Reynolds number and Grashof number; hence, it provides an excellent tool for forced, natural, and combined convection heat-transfer research. The Reynolds and Grashof numbers are increased with an ambient temperature of 80 K by factors of approximately 14 and 200, respectively, over those obtainable in a room temperature facility. The cryogenic environment virtually eliminates the influences of radiative heat transfer. The ability to vary the temperature in the test section greatly increases the range in the Reynolds and Grashof numbers that can be investigated with fixed model and test section dimensions. The cryogenic facility also provides an excellent environment for the investigation of the influences or property variations across the boundary layers.

*University of Illinois at Urbana-Champaign, Urbana, IL 61801 U.S.A.
Research Grant no. 87-9180

251. *Armstrong, E. S.; and *Tripp, J. S.: **An Application of Multivariable Design Techniques to the Control of the National Transonic Facility**. NASA TP-1887, August 1981, 34 pp., 4 refs.

N81-29840#

The digital versions of optimal linear regulator theory and eigenvalue placement theory are applied to the Mach number control loop of the U.S. National Transonic Facility cryogenic wind tunnel. The control laws developed are evaluated on a nonlinear simulation of the tunnel process for a typical test condition and are found to significantly reduce the open loop time required to achieve a Mach number set point.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

252. *Ladson, C. L.; and *Ray, E. J.: **Status of Advanced Airfoil Tests in the Langley 0.3-m Transonic Cryogenic Tunnel**. ACEE Project Oral Status Review, Dryden Research Center, September 14, 1981. Advanced Aerodynamics–Selected NASA Research, NASA CP-2208, (N84-27660), December 1981, pp. 37-53, 9 refs.

N84-27664#

A joint NASA/U.S. industry program to test advanced technology airfoils in the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) has been formulated under the NASA Langley ACEE Project Office. The objectives of this program include providing U.S. industry an opportunity to compare their most advanced airfoils to the latest NASA designs by means of high-Reynolds-number tests in the same wind tunnel. At the same time, industry will gain experience in the design and construction of cryogenic models as well as experience in cryogenic test techniques. This paper presents the status and details of the test program. Typical aerodynamic results are presented at chord Reynolds number up to 45 million and are compared to results from other facilities and theory. Details of a joint agreement between NASA and the DFVLR for tests of two airfoils are also included.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

253. *Blanchard, A.; *Dor, J.-B.; *Mignosi, A.; and *Breil, J. F.: **Research on an Induction Driven Cryogenic Wind Tunnel**. In: La Recherche Aerospatiale, Bulletin Bimestriel no. 1981-2, March-April 1981. Translation into English, ESA-TT-713, September 1981, pp. 63-77., 6 refs.

A81-43393#
or
N82-14394#

The cryogenitization of an induction-driven transonic wind tunnel is discussed. Internal insulation and the design of a liquid nitrogen injection system are considered. A unit of 32 injectors is arranged at the periphery of the first diffuser in two rows. Each injector is controlled by a solenoid valve. Several elements can be brought together at the control point to form a 10-bit digital regulation unit. The nitrogen pulses are kept symmetrical by varying the response time of the solenoid valves. This induction system works well, since the increase in nozzle performance compensates increase of flow in the test section due to the drop in temperature. It should be suitable with nitrogen gas. Composite and homogeneous insulating materials were repeatedly plunged into liquid nitrogen. All reveal defects when exposed to stress induced by differences in the expansion between their internal and external faces. Internal surfaces must be reinforced with polyurethane.

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254. *Hall, R. M.; and *Adcock, J. B.: **Simulation of Ideal-Gas Flow by Nitrogen and Other Selected Gases at Cryogenic Temperatures**. NASA TP-1901, September 1981, 51 pp., 19 refs.

N81-32418#

The real-gas behavior of nitrogen, the gas normally used in transonic cryogenic tunnels, is reported for the following flow processes: isentropic expansion, normal shocks, boundary layers, and interactions between shock waves and boundary layers. The only differences in predicted pressure ratio between nitrogen and an ideal gas which may limit the minimum operating temperature of transonic cryogenic wind tunnels occur at total pressures approaching 9 atm and total temperatures 10 K below the corresponding saturation temperature. These pressure differences approach 1 percent for both isentropic expansions and normal shocks. Alternative cryogenic test gases were also analyzed. Differences between air and an ideal diatomic gas are similar in magnitude to those for nitrogen and should present no difficulty. However, differences for helium and hydrogen are over an order of magnitude greater than those for nitrogen or air. It is concluded helium and cryogenic hydrogen would not approximate the compressible flow of an ideal diatomic gas.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

255. *McKinney, L. W.; and **Baals, D. D., editors: **High Reynolds Number Research-1980**. NASA CP-2183, September 1981, 325 pp.

N81-31130#

This is a compilation of papers presented at the Workshop on High Reynolds Number Research held December 9-11, 1980, at the NASA Langley Research Center. It also includes panel recommendations for research programs for the U.S. National Transonic Facility in the following areas:

- Fluid dynamics
- High lift
- Configuration aerodynamics
- Aeroelasticity and unsteady aerodynamics
- Wind-tunnel/flight correlation
- Space vehicles
- Theoretical aerodynamics

(A Workshop on High-Reynolds-Number Research was also held in 1976 and is reported in NASA CP-2009 (N77-27139), see citation nos. [47 through 50] in this bibliography.)

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**Joint Institute for Advancement of Flight Sciences, George Washington University, NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

256. *Lassiter, W. S.: **Design Predictions for Noise Control in the Cryogenic National Transonic Facility**. Noise Control Engineering, vol. 17, September - October 1981, pp. 76-84, 6 refs. (A paper on this subject was presented at Noise-Con 81 at North

Carolina State Univ., June 8-10, 1981, and is in their Proceedings, pp. 121-124, 3 refs. For a shortened form see Astronautics and Aeronautics, February 1981, p. 45.)

A82-12025

Noise control in the U.S. National Transonic Facility, a large, high-pressure cryogenic wind tunnel, has been examined in terms of acoustical design criteria, drive-fan noise, and exhaust system noise. A duct lining with two layers of perforated sheeting and a gas-filled honeycomb core was selected for attenuating drive-fan noise. With the exception of attenuation peaks, attenuation of the lining was found to experimentally agree with predicted values at 20 °C air temperatures. Exhaust system noise will be attenuated with a large muffler used with a 6.1-m high-acoustical enclosure. Fan noise from the fan-ejector system will be attenuated by fan silencers and the acoustic enclosure.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

257. *Polhamus, E. C.; and *Boyden, R. P.: **The Development of Cryogenic Wind Tunnels and Their Application to Maneuvering Aircraft Technology**. Presented at the AGARD Symposium on Combat Aircraft Maneuverability, Florence, Italy, October 5-8, 1981. In AGARD-CP-319, (N82-22187), pp. 15-1 through 15-12, 20 refs.

N82-22196#
or
A82-13971#

Because of the strong influence of Reynolds number, Mach number, and aeroelasticity on the aerodynamics of combat aircraft in the high angle-of-attack range encountered during maneuvers, the unique capabilities of the new cryogenic wind tunnels offer the aircraft designer important new capabilities for validation of his design methodology as well as the ability to isolate various effects. This paper discusses the cryogenic wind tunnel relative to its potential for advancing maneuvering aircraft technology. The first portion of the paper consists of a brief overview of the cryogenic wind-tunnel concept and the capabilities and status of the NASA Langley cryogenic wind tunnels. Included in this part is a review of the considerations leading to the selection of the cryogenic concept such as capital and operating costs of the tunnel, model and balance construction implications, and test conditions related to requirements specifically associated with maneuvering aircraft technology. Typical viscous, compressibility, and aeroelastic effects encountered by maneuvering aircraft are illustrated. The unique ability of the cryogenic wind tunnels to isolate and investigate these parameters while simulating full-scale conditions is discussed. The status of the NASA Langley cryogenic wind-tunnel facilities is reviewed and their operating envelopes described in relation to maneuvering aircraft research and development requirements. The final portion of the paper reviews the status of cryogenic testing technology development specifically related to aircraft maneuverability studies including force balances and buffet measurement techniques. Included are examples of research in the NASA Langley 0.3-m Transonic Cryogenic Tunnel to verify the various techniques.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

258. *Polhamus, E. C.: **The Large Second Generation of Cryogenic Tunnels**. Astronautics and Aeronautics, vol. 19, October 1981, pp. 38-51, 22 refs.

A81-48720#

Developmental histories and proven or projected operational capabilities are presented for wind tunnels, already operational or nearing completion, whose stream fluid is cryogenic and permits the testing of advanced transonic and supersonic aircraft designs at Reynolds numbers of up to 120 million. These wind tunnels include (1) the U.S. National Transonic Facility (NTF), which uses a conventional fan drive because of the drive-power reductions permitted by the cryogenic nitrogen stream fluid, (2) the Douglas Aircraft 4-ft trisonic tunnel, converted from conventional operation, and (3) the European Transonic Windtunnel (ETW), also a fan-driven cryogenic pressure tunnel. Also covered are cryogenic tunnels in France, Japan, Britain, and Germany. Attention is given the integration of digital control and data acquisition and processing capabilities into the cryogenic tunnels, such as the four identical computers of the NTF which are to increase productivity and reduce operating costs.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

259. *Clark, G. L., Jr.: **Cryogenic Modeling by Combined Convection From a Vertical Cylinder in a Horizontal Flow**. Univ. of Ill., Ph.D. thesis, October 1981, 209 pp., 85 refs.

N82-32632#

Prediction of the convective loss from solar thermal-electric receivers is not feasible since the scientific basis for such a prediction is not available. These receivers will typically operate in the combined convection region (Gr_L/Re_D^2-1) with Reynolds numbers, Re, above 10^6 and Grashof numbers, Gr, exceeding 10^{11}, well above previously reported experimental data. A novel heat-transfer technique, the use of cryogenic temperatures for convective modeling, was used in the present study to significantly extend the region of measured data for combined convection from a vertical cylinder in a horizontal flow. Reynolds numbers above 5×10^5, with Grashof numbers above 10^{11}, were achieved in a cryogenic heat-transfer tunnel constructed for this research.

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Research supported by Sandia Labs, Livermore, CA U.S.A.

260. *Clausing, A. M.; and *Kempka, S. N.: **The Influences of Property Variations on Natural Convection From Vertical Surfaces**. ASME Winter Annual Meeting, November 15-20, 1981, Washington, D.C., and published in the ASME "Natural Convection," HTD Vol. 16, 1981. Also published in Journal of Heat Transfer, vol. 103, no. 4, November 1981, pp. 609-612, 8 refs.

The objective of this paper is to show the influences of property variations in natural convection. Heat transfer from a vertical isothermal, heated surface to gaseous nitrogen is experimentally studied. The ambient temperature, T_f, is varied to cover a large range of the Rayleigh number and also to enable the generation of large values of this parameter. The range $80\ K < T_f < 320\ K$ results in Rayleigh numbers between 10^7 and 2×10^{10} for the 0.28 m model. By using a cryogenic environment, large ratios of the absolute temperature of the wall to the ambient temperature, T_w/T_f, are generated without the results being masked by radiative heat transfer. The range $1 < T_w/T_f < 2.6$ is studied. Variable properties cause dramatic increases in heat-transfer rates in the turbulent regime, and virtually no influence is seen in the laminar regime. The results obtained correlate extremely well with the addition of a single parameter T_w/T_f.

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Grant no. 87-9180, DOE Subcontract

261. *Morel, J. P.: **A Progress Report on the European Transonic Windtunnel Project** (Le Projet de Soufflerie Transsonique Europeenne ETW-Etat actual). Association Aeronautique et Astronomique de France, Colloque d'Aerodynamique Appliquee, 18th, Poitiers, France, November 18-20, 1981. ONERA TP-1981-121, 1981, 24 pp., 5 refs, in French.

A82-19737#

An interim report on the design for a European Transonic Windtunnel (ETW), being built by the cooperative efforts of France, Germany, Britain, and the Low Countries is presented and details of the partially completed prototype wind tunnel are provided. The ETW will be a cryogenic, nitrogen gas installation for examining flows at high-Reynolds numbers, and consultations are continuing with NASA on the cryogenic technology. The test section will have a 2.4 × 2 m^2 cross section, with a pressure range between 1.25-4.5 bars. Temperatures will range from 120-168 K at Mach numbers up to 1.7, and equipment altering the incidence angle of test models at a rate of 4 deg/sec is intended. A pilot ETW is under construction, with a cross-section of 0.27 × 0.23 m. It is to be used to verify the aerodynamic performance of the flow circuit, the responses to Mach number, pressure, and temperature, and the control circuits.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

262. *Tripp, J. S.: **An Algorithm for Minimum-Cost Set-Point Ordering in a Cryogenic Wind Tunnel.** NASA TP-1923, November 1981, 30 pp., 10 refs.

N82-11090#

An algorithm for minimum-cost ordering of set points in a cryogenic wind tunnel is developed. The procedure generates a matrix of dynamic state-transition costs, evaluated by means of a single-volume lumped model of the cryogenic wind tunnel and the use of some idealized minimum-cost state-transition control strategies. A branch and bound algorithm is employed to determine the least costly sequence of state transitions from the transition-cost matrix. Some numerical results based on data for the U.S. National Transonic Facility are presented which show a strong preference for state transitions that consume no coolant. Results also show the choice of the terminal set point in an open ordering can produce a wide variation in total cost.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

263. *Lawing, P. L.: **Vacuum-Brazed Joints for Cryogenic Wind-Tunnel Models.** Research and Technology-Annual Report of the NASA Langley Research Center, NASA TM-83221, November 1981, p. 7.

N82-13043

Nitronic 40 has been chosen for construction of pilot models to be used in the U.S. National Transonic Facility (NTF), a cryogenic wind tunnel. The ability to form bonded joints in Nitronic 40 is discussed and results are described. Highlights of major accomplishments and applications are presented in this annual report.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

264. *Johnson, C. B.: **Study of Nonadiabatic Boundary-Layer Stabilization Time in a Cryogenic Tunnel for Typical Wing and Fuselage Models.** Journal of Aircraft, vol. 18, no. 11, November 1981, pp. 913-919.

AIAA Paper 80-0417

Note: For an earlier form of this paper and an abstract see citation no. [179] in this bibliography.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

265. *Murthy, A. V.; *Johnson, C. B.; *Ray, E. J.; and *Lawing, P. L.: **Recent Sidewall Boundary-Layer Investigations With Suction in the Langley 0.3-m Transonic Cryogenic Tunnel.** AIAA 20th Aerospace Sciences Meeting, Orlando, Florida, January 11-14, 1982, 11 pp., 21 refs.

AIAA-82-0234 A82-17858#

An experimental and theoretical study of the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) sidewall boundary-layer with and without suction, has been made. Without suction, the boundary-layer displacement thickness at a station ahead of the model varied from about 1.6 to 1.3 mm over a Reynolds number range of 20 to 200 × 10^6/m at Mach numbers from 0.30 to 0.76. Measured velocity profiles correlated using the defect law of Hama. The boundary-layer displacement thickness decreased when suction was applied; however, after suction of about 2 percent of test section mass flow, the change in the thickness was small. A comparison of the measured suction effectiveness with finite difference and integral methods of boundary-layer calculation showed that both the methods predicted the right trend over the range of suction velocities (up to v_w/u_e = -0.02).

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

266. **L'ONERA a l'heure des Souffleries Cryogéniques.** (ONERA now has a cryogenic wind tunnel.) Aviation (International) Magazine, no. 818, January 15-31, 1982, pp. 28-32, in French.

ONERA has completed its transformation of the T2 tunnel. This tunnel, located at Centre d'Etudes et de Recherches de Toulouse (CERT), operates at very low temperatures in the neighborhood of 100 K (173 °C). The facility is described and insulating materials are discussed. The tunnel can attain a Reynolds number of 37 million with models of 150 mm. The wind tunnel also has adaptable walls.

267. *Beck, J. W.: **Cryogenic-Wind Tunnel Technology–A Way to Measurement at Higher Reynolds Numbers.** (Kryo-Windkanal-Technologie-Ein Weg zur Messung bei hNheren Reynolds-Zahlen.) In: Publication on the occasion of the 65th birthday of Prof. Dr.-Ing. Erich Trukenbrodt, Scientific Colloquium, Technische Universitat Munchen, Munich, Germany, February 1, 1982, Reports (A83-46482). Munich, Technische Universitat Munchen, 1982, pp. 53-87, 11 refs., in German.

A83-46484#

Note: For an English translation and an abstract of this paper see citation no. [379] in this bibliography.

*DFVLR–Wessling/Obb., Oberpfaffenhofen, D-8031 Wessling/Obb., FRG

268. *Teague, E. C.; *Vorburger, T. V.; *Scire, F. E.; *Baker, S. M.; *Jensen, S. W.; *Trahan, C.; and **Gloss, B. B.: **Evaluation of Methods for Characterizing Surface Topography of Models for High Reynolds Number Wind-Tunnels.** AIAA 12th Aerodynamic Testing Conference, Williamsburg, Va., March 21-24, 1982, 6 pp., 6 refs. Technical papers, pp. 246-251.

AIAA Paper 82-0603 A82-24675#

Because of the high Reynolds number of the U.S. National Transonic Facility (NTF) and the attendant thin boundary layers, NASA is re-examining aerodynamic effects related to model surface topography definition. There are no data which demonstrate the stylus instruments used by model fabrication shops accurately determine the topography of surfaces typical of NTF models. This paper describes current work at the National Bureau of Standards, sponsored by NASA, to evaluate the performance of stylus instruments for this application and to develop a light scattering instrument which will yield accurate characterizations of the surface microtopography and overcome the problems associated with stylus profilometry.

*National Bureau of Standards, Washington, DC 20324 U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

269. *Lynch, F. T.; and *Patel, D. R.: **Some Important New Instrumentation Needs and Testing Requirements for Testing in a Cryogenic Wind Tunnel Such as the NTF.** AIAA 12th Aerodynamic Testing Conference, Williamsburg, Va., March 21-24, 1982, 13 pp., 38 refs.

AIAA-82-0605

A great deal of effort has been focused on solving the actual construction and facility-related problems of cryogenic wind tunnels such as the U.S. National Transonic Facility (NTF). In contrast, however, inadequate attention has been given to the development of solutions to important user-related problems unique to cryogenic wind tunnels. To be able to exploit the potential advantage of the very high-Reynolds-number capability that will be provided by the NTF, several issues regarding instrumentation requirements and testing techniques must be addressed now. Two of the most important issues, largely ignored to date, concern the need for new boundary-layer transition fixing and detection methods for NTF models, and the need for precise model thermal conditioning and associated thermal control instrumentation. Another requirement which must be addressed is the need to provide provisions to establish model support interference effects. The rationale for these requirements in a cryogenic wind tunnel, and the urgency relative to the NTF is presented. All of these requirements will result in substantially higher model and testing costs than had been previously anticipated. Recommendations for near-term action by the technical community interested in effectively using the NTF are offered.

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270. *Fancher, M. F.: **Aspects of Cryogenic Wind Tunnel Testing Technology at Douglas.** AIAA 12th Aerodynamic Testing Conference, Williamsburg, Va., March 21-24, 1982, 11 pp., 29 refs.

AIAA Paper 82-0606

The need for high-Reynolds-number transonic aerodynamic testing capability appears near fulfillment with introduction of the cryogenic U.S. National Transonic Facility (NTF). To date, much emphasis has been placed on development of facility-related hardware and technology. Analysis and experience have shown, however, that a considerable number of user-related problems remain to be resolved before the NTF may be used either efficiently or effectively. The present paper describes the approach and experience at Douglas in further defining and seeking solutions to some of the outstanding testing problems facing users of the NTF. Subjects discussed include development of boundary-layer transition detection instrumentation, maintenance of model temperature tolerances, test section optical access, model materials, and model fabrication methods. (Copies may be obtained from the author.)

*Douglas Aircraft Co., McDonnell Douglas Corp., 3855 Lakewood Blvd., Long Beach, VA 90846 U.S.A.

271. *McKinney, L. W.; and *Gloss, B. B.: **Status of the National Transonic Facility.** Presented at the 12th AIAA Aerodynamic Testing Conference held in Williamsburg, Va., March 22-24, 1982, 11 pp., 16 refs.

AIAA Paper 82-0604 A82-33326#

The National Transonic Facility at NASA Langley Research Center, scheduled for completion in July 1982, is described with emphasis on model and instrumentation activities, calibration plans, and some initial research plans. Performance capabilities include a Mach number range of 0.2-1.2, a pressure range of 1-9 atm, and a temperature range of 77-350 K, which will produce a maximum Reynolds number of 120 million at a Mach number of 1.0, based on a 0.25 m chord. A comprehensive tunnel calibration program is planned, which will cover basic tunnel calibration, data qualities, and data comparisons with other facilities and flights.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

272. *Hunter, W. W., Jr.; and *Foughner, J. T., Jr., Editors: **Flow Visualization and Laser Velocimetry for Wind Tunnels.** A workshop held at NASA Langley Research Center, Hampton, Va., on March 25-26, 1982, NASA CP-2243, September 1982, 354 pp. Selected papers follow in this bibliography.

N82-32663#

The proceedings of a workshop held on March 25-26, 1982, at NASA Langley Research Center, are presented. The need for flow visualization and laser velocimetry were discussed. The purpose was threefold: (1) provide a state-of-the-art overview; (2) provide a forum for industry, universities, and government agencies to address problems in developing useful and productive flow visualization and laser velocimetry measurement techniques; and (3) provide discussion of recent developments and applications of flow visualization and laser-velocimetry measurement techniques and instrumentation systems for wind tunnels including the NASA Langley 0.3-meter Transonic Cryogenic Tunnel.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

273. *Crowder, J. P.: **Surface Flow Visualization Using Indicators.** Presented at a workshop on "Flow Visualization and Laser Velocimetry for Wind Tunnels," held at NASA Langley

Research Center, Hampton, Va., on March 25-26, 1982. In: NASA CP-2243, (N82-32663#), September 1982, pp. 37-46.

N82-32668#

Surface-flow visualization using indicators in the cryogenic wind tunnel which requires a fresh look at materials and procedures to accommodate the new test conditions is described. Potential liquid and gaseous indicators are identified. The particular materials illustrate the various requirements an indicator must fulfill. The indicator must respond properly to the flow phenomenon of interest and must be observable. Boundary layer transition is the most important phenomenon for which flow-visualization indicators may be employed. The visibility of a particular indicator depends on using various optical or chemical reactions. Gaseous indicators are more difficult to use, but because of their diversity may present unusual and useful opportunities. Factors to be considered in selecting an indicator include handling safety, toxicity, potential for contamination of the tunnel, and cost.

*Boeing Co., P. O. Box 3707, Seattle, WA 98124 U.S.A.

274. *Rhodes, D. B.; and *Jones, S. B.: **Flow Visualization in the Langley 0.3-meter Transonic Cryogenic Tunnel and Preliminary Plans for the National Transonic Facility**. Presented at a workshop on "Flow Visualization and Laser Velocimetry for Wind Tunnels," held at NASA Langley Research Center, Hampton, Va., on March 25-26, 1982. In: NASA CP-2243, (N82-32663#), September 1982, pp. 117-132.

N82-32677#

Design problems associated with the integration of flow visualization in cryogenic wind tunnels are discussed. The possible effects from the cryogenic environment (i.e., window distortion due to thermal contraction, both in the mounts and in the window material itself, and turbulence in the flow due to injected LN_2) are examined. The flow-visualization techniques studied are schlieren, shadowgraph, moiré deflectometry, and holographic interferometry. The test beds for this work are a NASA Langley in-house cryogenic test chamber and the 0.3-m Transonic Cryogenic Tunnel.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

275. *Snow, W. L.; *Burner, A. W.; and *Goad, W. K.: **"Seeing" Through Flows in Langley's 0.3-meter Transonic Cryogenic Tunnel**. Presented at a workshop on "Flow Visualization and Laser Velocimetry for Wind Tunnels," held at NASA Langley Research Center, Hampton, Va., on March 25-26, 1982. In: NASA CP-2243, (N82-32663#), September 1982, pp. 133-147.

N82-32678#

Viewing problems associated with the measurement of model deformation in cryogenic wind tunnels are discussed. Tests were made in the NASA Langley 0.3-m Transonic Cryogenic Tunnel to assess viewing capabilities through the flow field. The effects of condensation and turbulent boundary layers are discussed and a modeling procedure for image degradation is described.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

276. *Burner, A. W.; *Snow, W. L.; *Goad, W. K.; *Helms, V. T.; and *Gooderum, P. B.: **Flow Field Studies Using Holographic Interferometry at Langley**. Presented at a workshop on "Flow Visualization and Laser Velocimetry for Wind Tunnels," held at NASA Langley Research Center, Hampton, Va., on March 25-26, 1982. In: NASA CP-2243, (N82-32663#), September 1982, pp. 193-204.

N82-32682#

Some of the uses of holographic interferometry at NASA Langley Research Center both for flow visualization and for density field determinations are described. Tests in cryogenic flows at the NASA Langley 0.3-m Transonic Cryogenic Tunnel are discussed. Experimental and theoretical fringe shift data are compared.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

277. *Gartrell, L. R.: **Laser Doppler Velocimetry Application in the Langley 0.3-meter Transonic Cryogenic Tunnel**. Presented at a workshop on "Flow Visualization and Laser Velocimetry for Wind Tunnels," held at NASA Langley Research Center, Hampton, Va., on March 25-26, 1982. In: NASA CP-2243, (N82-32663#), September 1982, pp. 323-334, 3 refs.

N82-32696#

The problems and the potential use of a nonintrusive flow-velocity measuring technique in the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) were studied. A laser velocimeter (LV) was used. It was concluded free-stream velocity measurements can be successfully made in the NASA Langley 0.3-m TCT using a low-power (15-mW) LV system. The measured and calculated mean velocities typically agreed within one percent. The overall normalized standard deviation was less than one percent. Tunnel vibration and temperature had no detrimental effects on the optical system. The LV work should be further investigated for use in the NASA Langley 0.3-m TCT.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

278. *Honaker, W. C.: **Velocity and Flow Angle Measurements in the Langley 0.3-meter Transonic Cryogenic Tunnel Using a Laser Transit Anemometer**. Presented at a workshop on "Flow Visualization and Laser Velocimetry for Wind Tunnels," held at NASA Langley Research Center, Hampton, Va., on March 25-26, 1982. In: NASA CP-2243, (N82-32663#), September 1982, pp. 335-342.

N82-32697#

The Laser Transit Anemometer (LTA) system is described. In the LTA system two parallel laser beams of known separation and cross sectional area are focused at the same location or plane. When a particle in a flow field passes through both beams and the time is recorded for its transit (time of flight), its velocity can be calculated knowing the distance between the beams. By rotating the two beams (spots) around a common center and recording the number of valid events (a particle which passes through both spots in the proper sequence) at each angle, the flow angle can be determined by curve fitting a predetermined number of angles or points and calculating the peak of what should be a Gaussain curve. The best angle, flow angle, is defined as the angle at which the maximum number of valid events occurs. The LTA system functioned properly although conditions were less than desirable.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

279. *Hunter, W. W., Jr.; *Gartrell, L. R.; and *Honaker, W. C.: **Some NTF Laser Velocimeter Installation and Operation Considerations**. Presented at a workshop on "Flow Visualization and Laser Velocimetry for Wind Tunnels," held at NASA Langley Research Center, Hampton, Va., on March 25-26, 1982. In: NASA CP-2243, (N82-32663#), September 1982, pp. 343-358, 6 refs.

N82-32698#

Two velocimeter techniques were considered as potential candidates for achieving the flow-field angularity measurements. The first was the fringe laser Doppler velocimeter (LDV). A great deal of experience was obtained with this approach at NASA Langley and the literature is rich with papers describing many experimental applications and system performance details. That is, many velocity flow-field measurements were conducted with the LDV but not with high-resolution precise-angularity measurements. The second candidate considered was the two-spot laser transmit anemometer (LTA). This approach was not as extensively used as the LDV technique, but literature does contain experimental applications and system performance details. Again, a lack of high resolution, high-precision angularity measurements is noted for the LTA. The results of the study suggested the LDV and LTA tests and other efforts did not reveal any fundamental problems that would suggest laser velocimetry is not a viable diagnostic technique for the National Transonic Facility. However, there are a number of engineering problems that need to be solved.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

280. *Michel, R.; and *Mignosi, A.: **Adaptation and First Cryogenic Operation of T2 ONERA/CERT Wind Tunnel**. La Recherche Aerospatiale (English Edition), no. 2, March-April 1982, pp. 75-85, 5 refs.

A82-42531#
or
N84-13143#

A description is given of the transformation of the ONERA/CERT induction-driven transonic wind tunnel into a cryogenic wind tunnel which uses high-pressure air as a driving gas and liquid nitrogen as a coolant. An analysis of results from the first series of low-temperature tests shows the combination of induction and cryogenics yields steady and well defined low-temperature flows at transonic Mach numbers, with temperatures as low as 100 K and Reynolds numbers from 3 million to over 30 million. Attention is given to the design details of the liquid nitrogen supply and injection systems, as well as the performance levels achieved.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

281. *Wigley, D. A.: **The Metallurgical Structure and Mechanical Properties at Low Temperatures of Nitronic 40, With Particular Reference to its Use in the Construction of Models for Cryogenic Wind Tunnels**. NASA CR-165907, April 1982, 66 pp., 7 refs.

N82-30375

Nitronic 40 was chosen for the construction of Pathfinder I, an R & D model for use in the U.S. National Transonic Facility, because of its good published mechanical properties at cryogenic temperatures. Nitronic 40 delivered to NASA Langley Research Center (LaRC), McDonnell Douglas, and Lockheed was, however, found to contain delta ferrite and to be in a sensitized condition. Heat-treatments carried out at LaRC to remove residual stresses also caused further sensitization. Experiments showed heat-treatment followed by cryoquencing removed the sensitization without creating residual stresses. Heat-treatment at temperatures of 2200 °F was used to remove the delta ferrite but with little success and at the cost of massive grain growth. The implication of using degraded Nitronic 40 for cryogenic wind-tunnel models are discussed, together with possible acceptance criteria. It is suggested in the future it will be necessary to implement a policy of purchasing top-quality materials for cryogenic wind-tunnel models.

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Contract NAS1-16000

282. AGARD Fluid Dynamics Panel: **Windtunnel Capability Related to Test Sections, Cryogenics, and Computer-Windtunnel Integration**. April 1982, 66 pp.

Introduction – Dietz, R. O.[1], 2 pp.

Appendix 1 – Binion, T. W., Jr.[2]; Chevallier, J. P.[3]; and Laster, M. L.[4] (editor): Report of the Conveners' Group on **Transonic Test Technology**, 15 pp., 36 refs.

Appendix 2 – McKinney, L. W.[5]; North, R. J.[6]; and Polhamus, E. C.[7] (editor): Report of the Conveners' Group on **Cryogenic Test Technology**, 24 pp., 73 refs.

Appendix 3 – Firmin, M. C. P.[8]; Potter, J. L.[9]; and Green, J. E.[9] (editor): Report of the Conveners' Group on **Integration of Computers and Wind Tunnel Testing**. AGARD-AR-174, April 1982, 12 pp., 24 refs.

ISBN-92-835-1420-3 N82-29334#

The Advisory Report includes the results of six meetings sponsored by the Fluid Dynamics Panel and conclusions drawn from the reports prepared by the meeting chairmen. In each of the three subject areas, meetings were convened in the U.S. and Europe, with the results being combined by the chairmen. Applications of the technology discussed in this report can afford large improvements in wind-tunnel capability and effectiveness.

[1]University of Tennessee Space Institute, Tullahoma, TN 37388 U.S.A.
[2]Calspan Field Services, Inc., Arnold Air Force Station, TN 37389 U.S.A.
[3]ONERA, B.P. 72, F-92322 Châtillon Cedex, France
[4]Arnold Engineering Development Center (AEDC), Arnold Air Force Station, TN 37389 U.S.A.
[5]NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
[6]Technical Group ETW, c/o National Aerospace Laboratory, 1006 BM Amsterdam The Netherlands
[7]307 Mistletoe Drive, Newport News, VA 23606 U.S.A.
[8]Royal Aircraft Establishment, Farnborough, Hants GU14 6TD, England
[9]Ministry of Defence, 1 St. Giles High Street, London WC2 LD, England

283. *Hornung, H.; *Hefer, G.; *Krogmann, P.; and *Stanewsky, E.: Transsonische Kryo-messtrecke für den Göttingen Rohrwindkanal (**Transonic Cryogenic Test Section for the Göttingen Tube Facility**.) DFVLR Report no. IB-222-82 A19, May 3, 1982, 19 pp., 3 refs.

Note: For an English translation, see citation no. [332] in this bibliography.

The design of modern aircraft requires the solution of problems related to transonic flow at high Reynolds numbers. To investigate these problems experimentally, it is proposed to extend the Ludwieg tube facility in Göttingen by adding a transonic cryogenic test section. After stating the requirements for such a test section, the technical concept is briefly explained and a preliminary estimate of the costs is given.

*DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

284. *Young, C. P., Jr.; and *Gloss, B. B., compilers: **Cryogenic Wind Tunnel Models - Design and Fabrication**. Proceedings of a workshop held at NASA Langley Research Center, Hampton, Va., May 5-9, 1982. NASA CP-2262, March 1983, 266 pp.

N83-18748# through N83-18769#

The principal motivating factor was the U.S. National Transonic Facility (NTF). Since the NTF can achieve significantly higher Reynolds numbers at transonic speeds than other wind tunnels and will therefore occupy a unique position among ground test facilities, every effort is being made to be sure model design and fabrication technology exists to allow researchers to take advantage of this high-Reynolds-number capability. Since a great deal of experience in designing and fabricating cryogenic wind-tunnel models does not exist, and since the experience that does exist is scattered over a number of organizations, there is a need to bring existing experience in these areas together and share it among all interested parties. Representatives from government, the airframe industry, and universities are included. For individual titles, see N83-18749 through N83-18769 which are listed below.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

Overview of National Transonic Facility Model Technology Program. McKinney, L. W., pp. 1-10

Model Systems Criteria. Young, C. P., Jr., pp. 11-18, N83-18749#

NTF User Operations Requirements. Fuller, D. E., pp. 19-30, N83-18750#

Aspects of Fracture Mechanics in Cryogenic Model Design. Part I–Fundamentals of Fracture Mechanics. Hudson, C. M., pp. 31-40, N83-18751#

Aspects of Fracture Mechanics in Cryogenic Model Design. Part II–NTF Materials. Newman, J. C., Jr., and Lisagor, W. B., pp. 41-46, N83-18752#

Analytical Methods with Application to the Pathfinder I Model. Hunter, W. F., pp. 47-62, N83-18753#

Status of NTF Models. Bradshaw, J. F., pp. 63-70, N83-18754#

Status of Maneuverable-Fighter Model Design Study. Griffin, S. A., pp. 70-81

Lann Wing Design. Firth, G. C., pp. 83-85, N83-18755#

NTF Model: A New Breed. Whisler, W. C., pp. 87-90

NTF Model Concept for the X-29A. DaForno, G.; and Toscano, G., pp. 91-124, N83-18756# (Pt. 1) and N83-18757# (Pt. 2)

Cost Factors for NTF Models. Whisler, W. C., p. 125

Engineering and Fabrication Cost Considerations for Cryogenic Wind Tunnel Models. Boykin, R. M., Jr.; and Davenport, J. B., Jr., pp. 129-137, N83-18758#

Dimensional Stability Considerations for Cryogenic Metals. Wigley, D. A., pp. 139-143, N83-18759#

Metallic Alloy Stability Studies. Firth, G. C., pp. 145-153, N83-18760#

Metallurgical Studies of Nitronic 40 With Reference to its Use for Cryogenic Wind Tunnel Models. Wigley, D. A., pp. 155-176, N83-18761#

Cryogenic Materials Selection, Availability, and Cost Considerations. Rush, H. F., Jr., pp. 177-186, N83-18762#

Development of Tough, Strong, Iron-Base Alloy for Cryogenic Applications. Stephens, J. R., pp. 187-199, N83-18763#

Wire Electric-Discharge Machining and Other Fabrication Techniques. Morgan, W. H., pp. 201-203, N83-18764#

Surface Finish Measurement Studies. Teague, E. C., pp. 205-214, N83-18765#

Strain Gage Balances and Buffet Gages. Ferris, A. T., pp. 215-225, N83-18766#

Model Deformation System. Holmes, H. K., pp. 227-232, N83-18767#

NTF Model Pressure Measurements. Kern, F. A., pp. 233-243, N83-18768#

Angle of Attack System. Finley, T. D., pp. 245-256, N83-18769#
Panel Discussion Synopsis. p. 257

285. *Klich, P. J.; and *Cockrell, C. E.: **Mechanical Properties of a Fiberglass Prepreg System at Cryogenic and Other Temperatures**. AIAA Journal, vol. 21, December 1983, pp. 1722-1728. Presented at the AIAA/ASME/ASCE/AHS 23rd Structures, Structural Dynamics, and Materials Conference, New Orleans, La., May 10-12, 1982.

AIAA Paper 82-0708 A84-13580#

The test results given in this paper provide mechanical and physical properties of an epoxy E-glass system at cryogenic and elevated temperatures. E-glass cloth pre-impregnated with an epoxy resin was selected as the material for the fan blades in the U.S. National Transonic Facility (NTF). Because of the limited data available on E-glass at cryogenic temperatures, a testing program was undertaken at the NASA Langley Research Center to develop a data base to support the design of the NTF fan blades. The fan blades were made of 7781 and 7576 style E-glass cloths with EF-2 resin. Tests were made that characterize the strength and elastic properties of laminates made of each of the cloths, as well as of a laminate representative of the fan blade construction, at cryogenic, room, and elevated temperatures. In addition to these tests; creep, fatigue, and thermal expansion tests were made.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

286. *Wigley, D. A.: **Metallurgical Problems Encountered with Nitronic 40 Stainless Steel Intended for the Fabrication of Aerofoil Models for Cryogenic Wind Tunnels.** International Cryogenic Materials Conference, May 11-14, 1982, Kobe, Japan, pp. 25-28.

Nitronic 40, a 21 chromium-6 nickel-9 manganese-0.4 nitrogen austenitic stainless steel, was chosen for fabricating aerofoil models for cryogenic wind tunnels due to a combination of high strength and toughness at cryogenic temperatures and its ready availability in the required product forms. Material delivered to the NASA Langley Research Center (LaRC) and to a number of other U.S. Aerospace Corporations was, however, found to contain significant amounts of delta ferrite and to be in a sensitized condition. Heat-treatments carried out at LaRC to remove residual stresses also caused further sensitization. Experiments showed heat-treatment followed by cryoquenching removed the sensitization without creating residual stresses. Heat-treatment at temperatures of 2200 °F was used to remove the delta ferrite but with little success and at the cost of massive grain growth.

*University of Southampton, Department of Mechanical Engineering, Southampton, England
Contract NAS1-16000

287. *Kilgore, R. A.: **The Cryogenic Wind Tunnel for High Reynolds Number Testing.** Ninth International Cryogenic Engineering Conference, Kobe, Japan, May 11-14, 1982, pp. 389-394, 9 refs.

A82-33317

An improved way to increase the Reynolds-number capability of wind tunnels has been developed at the NASA Langley Research Center. Cooling the test gas to cryogenic temperatures by spraying liquid nitrogen into the tunnel circuit increases Reynolds number with no increase in dynamic pressure and a reduction in drive power. In addition, the ability to vary the temperature of the test gas independently of pressure and Mach number allows for the first time the independent determination of Reynolds number, Mach number, and aeroelastic effects. A new fan-driven transonic cryogenic tunnel being built at the NASA Langley Research Center will provide an order of magnitude increase in Reynolds-number capability over existing transonic tunnels in the United States when it is completed later this year.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

288. *Ito, K.; and *Saji, N.: **S-Foam Applied to Cryogenic Wind Tunnel.** International Cryogenic Materials Conference, Kobe, Japan, May 11-14, 1982, pp. 455-458.

A82-33316

Ishikawajima-Harima Heavy Industries Co., Ltd. is the sole manufacturer in Japan of cryogenic wind tunnels which are for research in the high-Reynolds-number regions. We have built three such tunnels, of which special attention will be directed to the one that we have delivered recently to the University of Tsukuba as it features our own internal insulation that promises a great saving of coolant and other advantages. A special plastic foam for cryogenic temperature, called S-foam, is used as the innermost lining of the tunnel body. This paper provides mainly the characteristics of this foam.

*Ishikawajima-Harima Heavy Industries Co., Ltd., Research Institute, Shin Ohtemachi Bldg., 2-1, 2-Chome, Ohtemachi, Chiyoda-Ku, Tokyo 100, Japan

289. *Kilgore, R. A.; and **Dress, D. A.: **The Cryogenic Wind Tunnel for High Reynolds Number Testing.** A lecture presented at the National Aerospace Laboratory, Chofu, Tokyo, Japan, May 20, 1982, 36 pp.

A82-33320#

This lecture provides an overview of the development of cryogenic wind tunnels and their application to high-Reynolds-number testing. The major portion is devoted to a review of the theory and advantages of cryogenic tunnels and a brief description of three of the applications of the cryogenic-tunnel concept, the Low-Speed Cryogenic Tunnel built at NASA Langley in 1972, the 0.3-m Transonic Cryogenic Tunnel built at NASA Langley in 1973, and the U.S. National Transonic Facility (NTF) under construction at NASA Langley and expected to be in operation before the end of 1982.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
**Kentron International, Inc., Hampton Technical Center, Hampton, VA 23665 U.S.A.

290. *Ray, E. J.: **A Review of Reynolds Number Studies Conducted in the Langley 0.3-m Transonic Cryogenic Tunnel.** AIAA/ASME 3rd Joint Thermophysics, Fluids, Plasma and Heat Transfer Conference, St. Louis, Mo., June 7-11, 1982, 14 pp., 26 refs.

AIAA-82-0941 A82-34007#

The NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) was first placed in operation as a pilot transonic cryogenic wind tunnel at the NASA Langley Research Center in 1973. As a result of its successful operation as the world's first transonic cryogenic pressure tunnel and its potential as a powerful new research tool, the pilot tunnel was later reclassified as a "permanent facility." During the period of operation of the 0.3-m TCT, an emphasis has been placed on the determination of Reynolds number effects on a wide variety of both two-dimensional and three-dimensional configurations. This paper reviews some of the Reynolds-number studies which have been made in the 0.3-m TCT and presents selected highlights obtained from these studies.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

291. *Takashima, K.; *Sawada, H.; and *Aoki, T.: **A Survey of the Three-Dimensional High Reynolds Number Transonic Wind Tunnel.** (Koku Gijutsu Kenkyujo Shiryo). English translation by Leo Kanner Associates, Redwood City, California of Japanese report NAL-TM-440, August 1981, NASA TM-76931, June 1982, 85 pp., 78 refs.

N83-23324#

Facilities for aerodynamic testing of airplane models at transonic speeds and high Reynolds numbers are surveyed. The need for high-Reynolds-number transonic testing is reviewed, using some experimental results. Some new approaches to high-Reynolds-number testing, i.e., the cryogenic wind tunnel, the induction-driven wind tunnel, the Ludwieg tube, the Evans clean tunnel and the hydraulic-driven wind tunnel are described. The level of development of high-Reynolds-number testing facilities in Japan is then discussed.

*National Aerospace Laboratory, 7-44-1 Jindaiji-machi Chofu-shi, Tokyo 182, Japan
NASA Contract NASw-3541 (for translation)

292. *Hall, R. M.; **Dotson, E. H.; and ***Vennemann, D. H.: **Homogeneous and Heterogeneous Condensation of Nitrogen in Transonic Flow.** Presented at the 13th International Symposium on Rarefied Gas Dynamics, Novosibirsk, USSR, July 5-9, 1982, 12 pp., 11 refs. (This paper was also given as Paper no. 24, at the Cryogenic Technology Review Meeting in Amsterdam, September 15-17, 1982.)

A82-43258#

Note: For a later version of this report see citation no. [318] in this bibliography.

Onset of both homogeneous and heterogeneous nucleation for nitrogen gas has been measured in the NASA Langley 0.3-m Transonic Cryogenic Tunnel. Homogeneous nucleation data have been taken using a DFVLR CAST-10 airfoil and are used to evaluate classical liquid droplet theory and several proposed corrections to it. A correction for differences in translation energy states between the droplet and the bulk liquid due to either Reiss (1977) or Kikuchi (1977) achieves good agreement between the predicted onset of nucleation and the data. Good agreement is also found using a Tolman constant of 0.25×10^{-10} m. Onset of heterogeneous nucleation of preexisting seed particles in the flow has also been studied, and preliminary estimates of seed size and number are 0.25×10^{-6} m and 3.0×10^{12} per kilogram of the gas. It is shown this preexisting seed population is insufficient to influence the observed onset of homogeneous nucleation.

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***DFVLR–Porz-Wahn, Postfach 90 60 58, D-5000 Köln 90 Porz-Wahn, FRG

293. *Wagner, B.: **Estimation of Simulation Errors and Investigations of Operating Range Extensions for the European Transonic Windtunnel (ETW). Final Rept., March 1981.** Rept. no. BMFT-FB-W-82-003, July 1982, 162 pp. 56 refs., in English.

N83-11152#

The influence of viscous effects in combination with real-gas effects and heat transfer at incorrectly cooled model surfaces is investigated with respect to the simulation accuracy in the planned cryogenic European Transonic Windtunnel (ETW). Changes in separation behavior and skin friction are calculated for the transonic shock-wave turbulent boundary-layer interaction by solving the full Navier-Stokes equations numerically and for profile flows by use of a nonadiabatic boundary-layer method. Both methods include a description of the real-gas behavior by the Beattie-Bridgeman equation. The results show no considerable differences for the separation behavior although always small systematic deviations in skin friction occur. In particular, the shock boundary-layer interaction process does not exhibit a special sensitivity. Two-dimensional calculations presented for the inviscid transonic flows with equilibrium condensations reveal small amounts of condensate are admissible without affecting the accuracy of the measurements; deviations become first visible for the drag coefficient. Concerning the possible operating range extensions for the ETW by using a favorable supersaturation effect, the computer program is capable of predicting the condensation onset and development including real-gas equations in the flow calculation. The program has been verified by application to hypersonic nitrogen jets with condensation corresponding to ETW stagnation conditions. But experimental results obtained by duplicating a typical ETW streamline are still needed to make the predictions fully reliable for ETW conditions. Furthermore, the theoretical results with respect to equilibrium condensation lead to additional validation of the streamline duplication idea.

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This research was sponsored by the German Ministry of Research and Technology under support number LVW 7901 and by the Technical Group ETW, Amsterdam, under contract ETW/79/01/68730/143963

294. *Wagner, B.: **Estimation of Simulation Errors in the European Transonic Windtunnel (ETW).** Presented at the 13th Council of the Aeronautical Sciences, and in Proceedings of AIAA Aircraft Systems and Technology Conference, Seattle, Wash., August 22-27, 1982, vol. 1, pp. 731-740, 22 refs.

ICAS-82-5.43 A82-40950#

Note: For another version of this presentation see citation no. [315] in this bibliography.

Simulation errors in cryogenic wind tunnels caused by real-gas effects, changes in viscosity and heat conductivity characteristics at low temperatures, heat transfer, and local condensation are estimated theoretically. For this purpose, viscous effects and heat-transfer influences in transonic high-Reynolds-number turbulent flows are calculated by solving numerically the full Navier-Stokes equations for shock-wave boundary-layer interactions and by calculating boundary layers on airfoils, real-gas equations of state and non-adiabatic walls being included in both procedures. Equilibrium condensation approximating the case of heterogeneous nucleation is investigated in transonic airfoil flows by numerical solutions of the full inviscid Euler equations. The separation behavior is shown not to be sensitive to real-gas effects and small amounts of heat transfer. The condensation influence is primarily shown by a considerable drag increase.

*Dornier GmbH–Friedrichshafen 1, Postfach 1420, D-7990 Friedrichshafen 1, FRG

This research was sponsored by the German Ministry of Research and Technology under support number LVW 7901 and by the Technical Group ETW, Amsterdam, under contract ETW/79/01 68730/143963

295. *Clausing, A. M.: **Advantages of a Cryogenic Environment for Experimental Investigations of Convective Heat Transfer.** In: International Journal of Heat and Mass Transfer, vol. 25, no. 8, August 1982, pp. 1255-1257, 2 refs.

Experimentalists studying convective heat-transfer phenomena often have difficulty in obtaining sufficiently large Reynolds numbers, *Re*, and/or Grashof numbers, *Gr*. A cryogenic environment, such as in a cryogenic wind tunnel, provides a means of obtaining, simultaneously, large increases in both the Reynolds number and the Grashof number; hence, it provides an excellent tool for forced, natural, and combined convective heat-transfer research. The Reynolds and Grashof numbers are increased with an ambient temperature of 80 K by factors of approximately 14 and 200, respectively, over those obtainable in a room temperature facility. The cryogenic environment virtually eliminates the influences of radiative heat transfer. The ability to vary the temperature in the test section greatly increases the range in the Reynolds and Grashof numbers that can be studied with fixed model and test section dimensions. The cryogenic facility also provides an excellent environment for the study of the influences of property variations across the boundary layers.

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296. *Gobert, J. L.; and *Mignosi, A.: **Studies on the Cryogenic Induction Driven Wind-Tunnel T2**. Paper no. 1 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982, 19 pp., 8 refs.

N83-28004#

The transonic-induction-driven wind-tunnel T2, with a testing section of 38 x 40 cm² pressurized up to 6 bars was transformed into a cryogenic system in 1981. The airflow is cooled by injecting liquid nitrogen in the wind tunnel. An internal insulation protects most of the tunnel elements and works with runs which last up to one minute. The method used for the run starting and the automatic control of the airflow parameters is described. A simplified process model allows a mini-computer centralizing all useful data to generate in real time the commands to initiate and stabilize the desired temperature and pressure values. The results defining the installation performances and airflow qualities are presented.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

297. *Dubois, M.: **Feasibility Study On Strain Gauge Balances for Cryogenic Wind Tunnels at ONERA**. Paper no. 2 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982. ONERA TP-1982-87, 1982, 20 pp., 14 refs.

A83-14539#

Ten dynamometric test pieces and a three-component sting balance were used in a study of cryogenic wind-tunnel strain-gauge technology, where the test pieces were made from different materials and fitted with two or three bridges composed of various types of strain gauges. The testing of the pieces under bending stresses reached a strain level of 1 mm/m, with cryogenic chamber temperatures in the 100-300 K range. On the basis of test results, materials were selected for the construction of the three-component balance, with balance architecture and gauge equipment designed to reduce the influence of temperature variations to a negligible level. The design of the balance allows it to be fitted with controlled heating devices, and will be calibrated in both cold and heated versions before certification trials in the ONERA/CERT cryogenic wind tunnel.

*ONERA, Modane Test Center, F-73500 Modane-Avrieux, France

298. *Francois, G.: **Thermal Behavior and Insulation of a Cryogenic Wind Tunnel**. Paper no. 3 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982. ONERA TP-1982-89, 1982, 19 pp., 6 refs.

A83-18427#

The thermal behavior of the structural elements of a cryogenic wind tunnel is examined along with the effects of thermal insulation on this behavior for the example of the planned continuous-flow European Transonic Windtunnel. Time constants for responses to stepwise variations in gas temperature are calculated for elements located in the gas flow itself (screens and corner turning vanes), walls exposed to the gas flow on a single face, and elements only indirectly subjected to gas-flow temperature variations (external walls and chamber supports). The wide range of time constants obtained is noted, and consequences for the thermal stresses of the structure are assessed. The attenuation of structural temperature variations by various types of internal insulation of the walls, which also allows more rapid changes in flow temperature and the reduction of energy consumption, is then considered. Possibilities for the thermal design of elements in the gas flow, the sting holder, test section walls and wind-tunnel walls are presented.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

299. *Fuijkschot, P. H.: **PEANUTS–The PETW Data System**. Paper no. 4 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982. NLR Rept. MAW-82-009-U, Memorandum AW-82-009 U, 14 pp.

N83-24519#

PEANUTS is centered around an HP-1000 computer system with 128 k words of RAM and 20 Mbyte of disc storage. The National Aerospace Laboratory (NLR) designed front end equipment including a digital 10 bus interface, 16 low level channels using 'conditioning units', an operator control panel, a scanivalve controller, and a 50-channel relay scanner. For temperature measurements with type-T thermocouples a high-precision unit with 60 Piltier cooled ice point reference junctions is available. The software for data acquisition is a proven NLR package with provisions for a monitoring loop and real-time display of computed values. Measured data are stored in well defined files, while the subsequent processing is primarily the responsibility of TG-ETW (Technical Group-European Transonic Windtunnel).

*National Aerospace Laboratory, 1006 BM Amsterdam, The Netherlands

300. *Graewe, E.: **Development of a Cryogenic Windtunnel Balance**. Paper no. 5, Part. 1, at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982. VFW Rept. KB-TE1-1173, 25 pp., 5 refs.

N83-31611#

The behavior of bending beams from maraging steel equipped with strain-gage bridges in the cryo-temperature-range is considered. Development of an unheated six-component balance for use in a cryogenic wind tunnel is considered.

*Vereinigte Flugtechnische Werke GmbH, Bremen, FRG

301. *Lorenz-Meyer, W.: **Development of a Cryogenic Wind Tunnel Balance**. Paper no. 5, Part 2 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982, 17 pp.

N83-25722#

A six-component wind-tunnel balance for cryogenic application was designed and built. A description is given of the design, instrumentation, and test setup.

*DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

302. *Schoenmakers, T. J.: **Development of a Non-Insulated Cryogenic Strain-Gauge Balance.** Paper no. 6 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982. NLR Rept. M-TP-82-006-U, 26 pp.

N83-24520#

Measurement of aerodynamic forces in the European Transonic Windtunnel (ETW) is done with strain-gage balances. The low and transient temperatures in this wind tunnel necessitate either keeping the balances at room temperature (heating and insulation) or developing special balances for cryogenic circumstances (non-insulated). Experiments leading to the development of a three-component cryogenic strain-gage balance are reviewed and discussed briefly.

*National Aerospace Laboratory, 1006 BM Amsterdam, The Netherlands

303. *Evans, J. Y. G.: **An Alternative Shape of Strain-Gauged Balance For Use in Wind Tunnels at Low-Temperatures.** Paper no. 7 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982, 19 pp., 2 refs.

N83-33124#

The search for a shape for a one-piece balance that might be more suitable than the conventional strain-gauge balance for general use in low-temperature wind tunnels led to a design with symmetry in both the pitch and yaw planes and with most of the drag stiffness concentrated at the axial location. Calculations of stress levels and deflection under load showed this design to have a performance similar to a modern conventional balance.

*Elven Precision Ltd., Crawley, England

304. *Law, R. D.: **Early Experience in Using the Cryogenic Test Facility at RAE Bedford, England.** Paper no. 8 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982, 14 pp.

N83-25726#

A closed circuit test duct has been built at RAE Bedford as part of the United Kingdom support for the ETW program. The maximum gas velocity through the 0.3-m square test section is 25 m/sec, falling with temperature. The gas temperature can be rapidly reduced and controlled at any level between ambient and 90 K by evaporation of liquid nitrogen. A simple calibration device is provided for loading small wind-tunnel balances mounted in the test duct. Some observations have been made of the behavior of a 3-component balance under transient temperature conditions.

*Royal Aircraft Establishment, Bedford, Beds MK41 6AE, England

305. *Bald, W. B.: **Temperature Response of a Model to Set-Point Changes and Conditioning in ETW.** Paper no. 9 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982, 28 pp.

N83-25721

Preliminary finite element thermal analysis of a model balance sting arrangement mounted in a cryogenic wind tunnel concluded heated balances were unacceptable if the model surface temperature was to satisfy the 1 percent adiabatic wall temperature condition specified by Green. The results of a more detailed finite element thermal analysis on an assumed 0.6 meter long stainless steel delta wing model supported by an unheated balance sting arrangement and subjected to the ETW set-point changes and temperature conditioning specified are summarized.

*Oxford University, Department of Engineering Science, Parks Road, Oxford OX1 3PJ, England

306. *Blanchard, A.; and *Mignosi, A.: **Problems Involved by the Instrumentation and the Conception of Cryogenic Tests.** Paper no. 10 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982, 14 pp., 8 refs.

N83-25725#

The studies carried out on small pressure transducers tested at cool temperature and the development of a probe used in T'3 (a small cryogenic transonic wind tunnel driven with a fan) are presented. An important point concerns the precooling of the model, necessary to obtain a temperature ratio T_w/T_{aw} near 1 during a run (20 to 40 seconds). This precooling is planned to be performed in a cooling box beside the test section; therefore, the model is introduced during the run starting process. To distinguish the effects due to the increase of Reynolds number, from those of specious conditions, the influence of various parameters must be discerned.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

307. *Paci, P.: **Practical Problems of Design and Manufacture of a 2-D Model and of the Device For Its Cooling and Introduction into the T2 Pressurized Cryogenic Intermittent Tunnel.** Paper no. 11 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982. ONERA TP-1982-88, 1982, 24 pp., 10 refs.

A83-14540#

A description is given of the design, fabrication, and operational problems which have been surmounted during the development of two-dimensional precooled models for use by the ONERA/CERT T2 cryogenic wind tunnel at Toulouse. The model must be at the tunnel airflow temperature from the outset of a cryogenic run to avoid thermal exchanges through its skin. This cooling of the model is accomplished in a separate model precooling box located to the side of the test section. A quick translation device integral with the precooling box is used to insert the model into the test section, where it is locked onto the incidence-determining apparatus and the desired pressure and speed are adjusted. Attention is given to the special design requirement for a 0.1-mm pressure tap diameter and the effects of thermomechanical deformations.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

308. *Schächterle, G.; *Ludwieg, H.; *Stanewsky, E.; and **Ray, E. J.: **Design and Construction of Two Transonic Airfoil Models for Tests in the NASA Langley 0.3-m TCT.** Paper no. 12 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982. NASA TM-85325, 1982, 28 pp., 7 refs.

N83-23326#

As part of a NASA/DFVLR cooperation program, two transonic airfoils were tested in the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT). Model design and construction were carried out by DFVLR. The models performed extremely well under cryogenic conditions. Essentially no permanent changes in surface quality and geometric dimensions occurred during the tests. The aerodynamic results from the 0.3-m TCT tests, which demonstrate the large sensitivity of the airfoil CAST 10-2/DOA2 to Reynolds number changes, compared well with results from other tunnels at ambient temperatures.

*DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

309. *Zacharias, A.: **Parameter and Design Studies for the Use of Wind Tunnel Models in the ETW**. Paper no. 13 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982. Rep. no. MBB/FE 123/S/PUB/83, 13 pp., 7 refs.

N83-24518#

The boundary conditions and the design criteria for cryogenic wind-tunnel models were analyzed for a Tornado model in terms of their experimental and design problems. Some fundamental relationships concerning fluid mechanics for cryogenic wind tunnels, as well as several experimental and model related considerations, were summarized as formulae.

*Messerschmitt-Bölkow-Blohm GmbH–München, Postfach 801109, D-8000 München 80, FRG

310. *Bazin, M.: **Sting Line Feasibility for Force Measurements in the European Wind Tunnel**. Paper no. 14 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982. ONERA TP-1982-90, 1982, 20 pp., 3 refs.

A83-14541#

Apparent contradictions among published results concerning stagnation pressure limitations in model supports for the European Transonic Windtunnel (ETW) have prompted the present parametric analysis to be sure the sting-line mounting of the models and accurate force measurements will be possible at high-pressure levels and transonic speeds. The modeling technique used in the analysis uses base diameter and aspect ratio as parameters and makes possible a representation of numerous sting lines with two types of balances. The pressure limitations identified are due to balance capacities, strains, static divergence risk, and model base gap. These have been calculated for the cases of the Airbus airliner and Mirage 2000 fighter aircraft at a scale well adapted to the ETW test section. A dimensional analysis makes possible the use of these results for every homothetical geometry.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

311. *Hoenlinger, H.; and *Mussmann, D.: **Some Aspects of Aeroelastic Models for Cryogenic Wind Tunnels**. Paper no. 16 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982. Rept. no. MBB/FE294/S/PUB/80, 28 pp.

X83-74856

*Messerschmitt-Bölkow-Blohm GmbH–Ottobrunn, Postfach 801220, D-8000 Ottobrunn, FRG

312. *Schimanski, D.: **Investigations and Tests of Mechanisms for Wind Tunnel Models Under Cryogenic Test Conditions.** Paper no. 17 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982. Rept. no. M/FE125/S/PUB/78 and DCAF F070087, 28 pp., 7 refs.

X83-74560

*Messerschmitt-Bölkow-Blohm GmbH–Ottobrunn, Postfach 801220, D-8000 Ottobrunn, FRG

313. *Petitniot, J. L.; and *Dupriez, F.: **Materials and Modeling Technology for Cryogenic Environment**. Paper no. 18 at the ETW Cryogenic Technology Review Meeting, NLR- Amsterdam, September 15-17, 1982, 41 pp., 32 refs.

N83-25723#

Construction of a model and its support for use in a cryogenic wind tunnel induces problems relative to the choice of the following: materials for the different model parts, lifting areas, fuselage, balance and sting line, construction techniques depending on the aim of the tests to be done, joints between model and its support, joints between model support and wind-tunnel structure, and isolated or nonisolated onboard instrumentation. According to the type of tests, solicitations on the model in the test section will be very variable. For static tests, aimed at the determination of aerodynamic coefficients, maximum stress levels were fixed, with the agreement of air frame designers, to 400 MPa for civil and 800 MPa for fighter models. A dynamic stress is added to the static one whose value is of the order of 20 percent of the static stress. The frequency range lies beyond 30 to 50 Hz. As an example, for a Mirage delta 2000 classic 1/8 scale model, first wing flexure mode is about 100 Hz. At this level, the balance stiffness effect becomes preponderant and the first frequencies met in the wind tunnel are those of the rigid modes of the model on its support.

*ONERA/IMFL, 5 Boulevard Paul Painlevé, 59000-Lille, France

314. *Luck, S.: **Experimental Tests on Accelerometers and Pressure Transducers for Cryogenic Wind-Tunnel Models**. Paper no. 20 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982. Rept. no. M/FE123/S/PUB/77, 22 pp., 4 refs.

N83-24517#

The function of accelerometers and pressure transducers in simulated conditions was shown, and demonstration of probes which might be used was given.

*Messerschmitt-Bölkow-Blohm GmbH–Ottobrunn, Postfach 801220, D-8000 Ottobrunn, FRG

315. *Wagner, B.: **Estimation of Simulation Errors in the European Transonic Windtunnel (ETW)**. Paper no. 21 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982, 10 pp., 22 refs.

Note: For another presentation with the identical title and an abstract, see citation no. [294] in this bibliography.

*Dornier GmbH–Friedrichshafen 1, Postfach 1420, D-7990 Friedrichshafen 1, FRG

This research was sponsored by the German Ministry of Research and Technology under support number LVW7901 and by the Technical Group ETW, Amsterdam, under contract ETW/79/01/68730/143963

316. *Dueker, M.: **Condensation Studies in Cryogenic Nitrogen Expansions**. Paper no. 22 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982, 14 pp., 4 refs.

N83-25720#

The Reynolds number range of wind tunnels is extended to higher values when the wind tunnel operates under cryogenic conditions. With a stagnation temperature chosen too low, the gas may expand into its liquid or solid phase region, which will cause condensation effects. Avoiding impurities in the test gas will prevent heterogeneous condensation, but in an isentropic expansion, far enough into the liquid or solid phase region, homogeneous condensation will occur. The determination of condensation onset points in isentropic expansions around realistic airfoils is tested in the European Transonic Windtunnel (ETW). Real-gas effects in cryogenic flows are not described.

*DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

317. *Viehweger, G.: **The Cryogenic Wind Tunnel Cologne**. Paper no. 23 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982, 21 pp.

N83-25724#

The low-speed wind tunnel in its original conception had a closed circuit and an open test section with a cross sectional area of about 7 m^2. After the cryogenic modification, the tunnel has an internal insulation and a closed test section of 2.4 × 2.4 m. The gas temperature is varied between 300 and 100 K by injecting liquid nitrogen. The velocity is in the range of about 5 to 100 m/s, depending on the actual temperature. Cooling down the tunnel increases the maximum Reynolds number to more than 8 million.

*DFVLR–Porz-Wahn, Postfach 90 60 58, D-5000 Köln 90 Porz-Wahn, FRG

318. *Hall, R. M.; **Dotson, E. H.; and ***Vennemann, D. H.: **Homogeneous and Heterogeneous Condensation of Nitrogen in Transonic Flow**. Paper no. 24 at the ETW Cryogenic Technology Review Meeting, NLR-Amsterdam, September 15-17, 1982.

A82-43258#

Note: For a previous presentation of this paper and an abstract, see citation no. [292] in this bibliography.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
**George Washington University, NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
***DFVLR–Porz-Wahn, Postfach 90 60 58, D-5000 Köln 90 Porz-Wahn, FRG

319. *Singh, J. J.; *Marple, C. G.; and *Davis, W. T.: **Characterization of Particles in the Langley 0.3-Meter Transonic Cryogenic Tunnel Using Hot Wire Anemometry**. NASA TM-84551, September 1982, 18 pp., 9 refs.

N83-10407#

Hot-wire anemometry was used to identify the nature of particles reportedly observed during free-stream velocity measurements in the NASA Langley 0.3-m Transonic Cryogenic Tunnel using a Laser Doppler Velocimeter. Since the heat-transfer process from the hot wire depends on the thermal conductivity and sticking capability of the particles, it was anticipated the hot-wire anemometer response would be affected differently upon impaction by liquid droplets and solid aerosols in the test gas stream. Based on the measured time response of the hot wire anemometer in the cryogenic tunnel operated in the 0.3-0.8 Mach number range, it is concluded the particles impacting the hot wire are liquid rather than solid aerosols. It is further surmised the liquid aerosols are unevaporated liquid nitrogen droplets used for cooling the tunnel test gas.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

320. *Thibodeaux, J. J.: **Sensitivity Analysis of Cool-Down Strategies for a Transonic Cryogenic Wind Tunnel**. NASA TM-84527, September 1982, 29 pp., 9 refs.

N83-10082#

This paper gives guidelines and suggestions confirmed by real-time simulation data to ensure optimum time and energy use of injected liquid nitrogen for cooling the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT). It is directed toward enabling operators and researchers to use the 0.3-m TCT in an energy- or time-efficient manner. The recommendations made herein, if followed, will result in minimum time and liquid-nitrogen usage during tunnel cool-down. These operational recommendations have been developed based on information collected from a validated simulator of the 0.3-m TCT and experimental data from the tunnel. Results and trends, however, can be extrapolated to other similarly constructed cryogenic wind tunnels.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

321. *Wigley, D. A.: **The Problem of Dimensional Instability in Airfoil Models for Cryogenic Wind Tunnels**. NASA CR-166003, September 1982, 25 pp., 13 refs.

N83-13229#

The problem of dimensional instability in airfoil models for cryogenic wind tunnels is discussed in terms of the various mechanisms that can be responsible. The interrelationship between metallurgical structure and possible dimensional instability in cryogenic usage is discussed for those steel alloys of most interest for wind-tunnel model construction. Other basic mechanisms responsible for setting up residual stress systems are discussed, together with ways in which their magnitude may be reduced by various elevated or low-temperature thermal cycles. A standard specimen configuration is proposed for use in experimental studies into the effects of machining, heat treatment, and other variables that influence the dimensional stability of the materials of interest. A brief classification of various materials in terms of their metallurgical structure and susceptibility to dimensional instability is presented.

*University of Southampton, Department of Mechanical Engineering, Southampton SO9 5NH, Hampshire, England
Contract NAS1-16000

322. *Leistner, R.; *Zacharias, A.; *Schimanski, D.; **Esch, P.; **Joos, R.; and **Thiel, E.: **Design and Manufacture of a Transonic Windtunnel Model and the Investigation of Model Components Under Cryogenic Flow Conditions in the European Transonic Windtunnel. Final Report, September, 1981.** Bundesministerium für Forschung und Technologie, BMFT-FB-W-82-015, September 1982, 113 pp., 21 refs.

ISSN-0170-1339 N83-13078#

A Tornado model wing with high-lift devices is described. This work demonstrates we can build models for the European Transonic Windtunnel which exhibit the critical aerodynamic characteristics for a design Reynolds number of 40 million. Stress, design life, safety factors, and mechanical and physical properties of design elements are discussed. Test data for maraging and austenitic steel elements are presented.

*Messerschmitt-Bölkow-Blohm GmbH–München, Postfach 801109, D-8000 München 80, FRG
**Dornier GmbH–Friedrichshafen 1, Postfach 1420, D-7990 Friedrichshafen 1, FRG
Sponsored by Bundesministerium für Forschung und Technologie (BMFT) Bonn, FRG

323. *Boyden, R. P.; and *Johnson, W. G., Jr.: **Results of Buffet Tests in a Cryogenic Wind Tunnel.** NASA TM-84520, September 1982, 49 pp., 15 refs.

N82-33342#

Buffet tests on two semispan-wing models with different leading-edge sweep have shown it is feasible to use the standard dynamic wing-root bending-moment technique in a cryogenic wind tunnel. One model was a slender 65°-swept delta wing with sharp leading edges. The other model was an unswept wing of aspect ratio 1.5 with a British NPL 9510 airfoil section. The results for the 65°-swept delta wing show the importance of matching the reduced-frequency parameter if quantitative buffet measurements are required. The unique ability of a pressurized cryogenic wind tunnel to separate the effects of Reynolds number and of static aeroelastic distortion by variations in the tunnel stagnation temperature and pressure has been demonstrated.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

324. Shchelkunov, V. N.; Rudenko, N. Z.; and Fofelov, M. A.: **Cryogenic Wind Tunnel of Variable Density at low Reynolds Numbers.** In: Pribory i Tekhnika Eksperimenta, no. 5, September-October 1982, pp. 230-237, in Russian.

X88-70703

Note: Contact the NASA Langley Research Center technical library for possible translations of this report.

325. *Webster, T. J.: **A Report on Possible Safety Hazards Associated With the Operation of the 0.3-m Transonic Cryogenic Tunnel at the NASA Langley Research Center.** NASA CR-166026, October 1982, 11 pp.

N83-14140#

The NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) was built in 1973. It was intended to be used for no more than 60 hours to verify the validity of the cryogenic wind-tunnel concept at transonic speeds. The role of the 0.3-m TCT has gradually changed until now, after over 3000 hours of operation, it is classified as a major NASA research facility. Under the administration of the Experimental Techniques Branch, it is used extensively for the testing of airfoils at high Reynolds numbers and for the development of various technologies related to the efficient operation and use of cryogenic wind tunnels. This report documents the results of a safety analysis of the 0.3-m TCT. The analysis was made as part of an ongoing program with the Experimental Techniques Branch designed to ensure the existing equipment and current operating procedures of the 0.3-m TCT are acceptable in terms of today's standards of safety for cryogenic systems.

*Applied Cryogenics and Materials Consultants, Inc., 15 Cantamar Court, Hampton, VA 23664 U.S.A.

326. *Burner, A. W.; and *Goad, W. K.: **Flow Visualization in a Cryogenic Wind Tunnel Using Holography.** NASA TM-84556, November 1982, 20 pp., 5 refs.

N83-12395#

Note: For another form of this report see citation no. [345] in this bibliography.

Results of holographic flow visualization are presented from tests made in the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT), which was operated over a temperature range from 100 to 300 K and a pressure range from 1.1 to 4.0 atm. Interferometry at the 0.3-m TCT may be of limited use at the low-temperature, high-pressure conditions because of the jumbled nature of the reference fringes. The shadowgraph technique appears to be the best means of visualizing shocks at these high-density conditions. The spot size at the focus of the reconstructed beams was measured and used as an indicator of density fluctuations in the flow field. These density fluctuations appear to be caused by temperature fluctuations of the test gas which are relatively independent of tunnel conditions.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

327. *Snow, W. L.; *Burner, A. W.; and *Goad, W. K.: **Image Degradation in Langley 0.3-Meter Transonic Cryogenic Tunnel.** NASA TM-84550, November 1982, 24 pp., 9 refs.

N83-13419#

The optical quality of gas in a cryogenic wind tunnel was determined by observing Sayce targets through different pathlengths of the test gas. The data was used to determine the square wave response of the test gas. At conditions corresponding to 15 times ambient density, considerable decrease in response to higher spatial frequencies was noted even in the absence of flow. Under flow conditions, vibrations further degraded the response. The results are interpreted in terms of possible photogrammetric approaches to measure model deformation in large cryogenic wind tunnels such as the U.S. National Transonic Facility.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

328. *Hoenlinger, H.; *Luck, S.; and *Schimanski, D.: **Basic Investigations for the Use of Wind Tunnel Models in the ETW. Final Report, September 1981.** Bundesministerium für Forschung und Technologie, BMFT-FB-W-82-023, MBB/FE123/S/STY/0042. December 1982, 49 pp., 6 refs., in English.

ISSN-0170-1339 N83-24522#

The use of wind-tunnel models at cryogenic temperatures places new demands on the equipment, instruments, and methods of construction applied hitherto. Their suitability is examined and recommendations are derived which should be observed in building and instrumenting wind-tunnel models for cryogenic testing. In addition, methods are pointed out which allow, with some degree of convenience, an economical test procedure suited to the ETW. The report is divided into the following three main subjects: (1) Instrumentation, (2) Mechanisms and Manipulators, and (3) Aeroelastic and Dynamically Similar Models. In order to execute the experimental face of the project, a cryogenic chamber was ordered in which the temperature range of the ETW could be simulated in a working volume of $100 \times 50 \times 50$ cm^3.

*Messerschmitt-Bölkow-Blohm GmbH–Ottobrunn, Postfach 801220, D-8000 Ottobrunn, FRG
Sponsored by Bundesministerium für Forschung und Technologie

329. *Archambaud, J.-P.: **Calcul de L'Evolution du Champ des Temperatures dans un Element Mettallique Paroi-Raidisseur au Cours d'une Rafale Cryogenique.** (Computation of the evolution of the temperature field in the metal piece wall-stiffener during a cryogenic run). RTOA no. 25/3075 AND (DERAT n° 8/5015 DN), December 1982, 17 pp., 9 figs., 3 refs., in French.

DCAF F070143 N89-70910

This paper deals with the theoretical behavior of classical flexible walls (metallic, not insulated) during a cryogenic run carried out at the T2 wind tunnel of ONERA/CERT. This is an unsteady coupling calculation: boundary layer on the internal side-heat transfer throughout a piece of wall involving a stiffener. This calculation provides as a function of time the following: the local variations of the thermal fluxes at the wall, the temperature field into the wall, and the boundary layer which will be taken into account by the wall adaptation process.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

330. *Wagner, B.: **Boundary Layer Calculations for Cryogenic Wind Tunnel Flows**. Recent Contributions to Fluid Mechanics, Springer-Verlag, (Berlin), 1982, pp. 283-293, 16 refs.

A83-46478

The possible changes in the separation behavior of flows over airfoils in a cryogenic wind tunnel due to alterations in the wall temperature from thermodynamic gas effects and a slope change of the viscosity were investigated. Nitrogen was considered as the working fluid and attention was also given to nonadiabatic effects of walls without a predicted recovery temperature. The theoretical analysis was used to assess the effects of the wall temperature changes and the slope change on separation in high-Reynolds-number transonic flows. A boundary-layer model was developed which takes the nonadiabatic and real-gas effects into account. Changes in the wall temperature of up to 20 percent produced only negligible changes in the skin-friction drag.

*Dornier GmbH–Friedrichshafen 1, Postfach 1420, D-7990 Friedrichshafen 1, FRG
Contracts BMFT-LVW-9901 and ETWT-79/01/68730/143963

331. *Japan Steel Works, Ltd.: **9% Ni Steel**. 1982, 16 pp.

This brochure describes the production at Japan Steel Works, Ltd., of three of the major components of the U.S. National Transonic Facility (NTF), namely the drive shaft, the fan disc, and the angle-of-attack arc sector. The following are included in the contents: specifications; manufacturing practice; internal quality; mechanical properties; susceptibility to temper embrittlement; fracture toughness; and manufacturing experience (1) hollow shaft forging, (2) disc forging, and (3) arc shape forging.

*Japan Steel Works America, Inc., 200 Park Ave., New York, NY U.S.A.

332. *Hornung, H.; *Hefer, G.; *Krogmann, P.; and *Stanewsky, E.: **Transonic Cryogenic Test Section for the Göttingen Tube Facility**. NASA TM-77050, March 1983. Translation into English of German DFVLR Rep. no. IB-222-82A19, May 3, 1982, 19 pp., 3 refs.

N84-16219#

Note: For the original German report see citation no. [283] in this bibliography.

The design of modern aircraft requires the solution of problems related to transonic flow at high Reynolds numbers. To investigate these problems experimentally, it is proposed to extend the Ludwieg tube facility in Göttingen by adding a transonic cryogenic test section. After stating the requirements for such a test section, the technical concept is briefly explained and a preliminary estimate of the costs is given.

*DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

333. *Young, C. P.; and *Gloss, B. B., compilers: **Cryogenic Wind Tunnel Models. Design and Fabrication.** Proceedings of a workshop held at NASA, Hampton, Va., May 5-9, 1982. NASA-CP-2262, March 1983, 254 pp.

N83-18748#

Note: For a list of the papers presented see citation no. [284] in this bibliography.

The principal motivating factor was the National Transonic Facility (NTF). Since the NTF can achieve significantly higher Reynolds numbers at transonic speeds than other wind tunnels in the world, and will therefore occupy a unique position among ground test facilities, every effort is being made to ensure that model design and fabrication technology exists to allow researchers to take advantage of this high-Reynolds-number capability. Since a great deal of experience in designing and fabricating cryogenic wind-tunnel models does not exist, and since the experience that does exist is scattered over a number of organizations, there is a need to bring existing experience in these areas together and share it among all interested parties. Representatives from government, the airframe industry, and universities are included.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

334. *Gobert, J. L.; and *Breil, J. F.: **Preliminary Study of an Apparatus to Control the Temperature of the Flow Entering the T2 Cryogenic Wind Tunnel. (Etude preliminaire d'un dispostif de controle de la temperature de l'ecoulement destine a la**

soufflerie cryogenique T2). ONERA-CERT R.T. OA 20/5007, April 1983, 37 pp., 6 refs., in French.

Note: For English translation of this paper see citation no. [485] in this bibliography.

The use of intermittent cryogenic wind tunnels makes it necessary to control the flow parameters of temperature, pressure, and speed. This report gives the results of a preliminary study done in the CERT T'2 wind tunnel. The feasibility of a temperature control apparatus which uses a real time mini-computer is shown.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

335. *Esch, P.; and **Leistner, R.: **Studien zur modell-technologie im ETW. Studies Concerning Model Technology in the European Transonic Windtunnel (ETW).** Paper presented at Bundesministerium fur Forschung und Technologie, 3rd Statusseminar uber Luft-fahrtforschung und Luftfahrttechnologie. Hamburg, Germany, May 2-4, 1983, 42 pp., in German.

A83-47197#

Attention is given to a model design study to determine the feasibility of a simulation of the aerodynamic aircraft properties in the transonic velocity range under the cryogenic flow conditions of the ETW. The study is concerned with general configuration considerations for current and future aircraft and parameter and material studies. In addition, the practicality of simulation studies in the ETW is looked at for the military aircraft Tornado. A project description is provided, and test conditions in the ETW are discussed along with the model scale, the accuracy requirements, the characteristics of the model, recommendations for material selection, special materials for flutter models, a cryogenic test chamber, the model mechanisms, and predesign work related to the Tornado model.

*Dornier GmbH–Friedrichshafen 1, Postfach 1420, D-7990 Friedrichshafen 1, FRG
**Messerschmitt-Bölkow-Blohm GmbH–Ottobrunn, Postfach 801220, D-8000 Ottobrunn, FRG

336. *Maurer, F.; and *Viehweger, G.: **Statusbericht zum Europaischen Transschall Windkanal und zum Kryo-Kanal-Köln. Status Report on the European Transonic Windtunnel and on the Cologne Cryotunnel.** Paper presented at Bundesministerium fur Forschung und Technologie, 3rd Statusseminar uber Luftfahrtforschung und Luftfahrttechnologie, Hamburg, Germany, May 2-4, 1983, 42 pp., in German.

A83-47207#

Planned revisions of the design of the European Transonic Windtunnel are reported, emphasizing the planned enlargement of the tunnel and the financing of needed alterations. The revisions include the cancellation of an expensive pressure lock and possible alternatives involving compartmentalization of the measurement chamber. The possibility of supplementary internal insulation to deal with fatigue problems caused by fast variations in temperature is considered. The energy requirements of various phases of the project, the building costs, and the planned mean discharge plan are discussed.

*DFVLR–Porz-Wahn, Postfach 90 60 58, D-5000 Köln 90 Porz-Wahn, FRG

337. *Ewald, B.; and **Graewe, E.: **Entwicklung einer 6-Komponenten-Waage fur den Kryo-Bereich. Development of a Six-Component Balance for Cryogenic Applications.** Paper presented at Bundesministerium für Forschung und Technologie, 3rd Statusseminar uber Luftfahrtforschung und Luftfahrttechnologie, Hamburg, Germany, May 2-4, 1983, 33 pp., in German.

A83-47208#

The design and manufacture of an unheated 6-component balance for the model sting of a cryogenic wind tunnel are discussed. The application requires a compact device capable of bearing heavy loads and remaining accurate at temperatures from 90 to 320 K. The device constructed used electron-beam welded maraging steel for the body, type-WK wire-strain gauges, epoxy-resin glue and coating material. Materials testing at different temperatures and temperature gradients is summarized. Drawings and photographs of the device are shown. The design of the calibration shell is described. The errors in the measurement of axial forces which arose due to temperature gradients are corrected by means of software, which takes the measured temperature distribution in the device into account, thus accounting for even nonlinear effects.

*Technische Hochschule Darmstadt, Karolinenplatz 5, D-6100 Darmstadt, FRG
**Vereinigte Flugtechnische Werke GmbH, Bremen, FRG

338. *Edwards, H. B.: **Design Refinements in Multi-Component Strain Gage Balances.** Presented at the 29th International Instrumentation Symposium, Albuquerque, New Mex., May 2-6, 1983. In: Proceedings (A85-29551), Research Triangle Park, NC, Instrument Society of America, 1983, pp. 227-235, 1 ref.

A85-29561

Because of increasingly severe conditions in wind-tunnel testing such as, heavy loads on small models, high lift-to-drag ratios and cryogenic environment, three problems still plague strain gage balances: interactions, joints, and temperature gradients. Although interactions can be corrected by calibration and computing, they can be reduced by eliminating unsymmetrical cross-section changes in the balance and by proper location of gages. While joints in balances can be eliminated by electrical discharge machining, the joints from model to balance, and balance to support, can be improved by isolating balance elements from fasteners and by use of orthogonal flat surfaces requiring no dowels. Balances are routinely compensated for uniform temperatures, but temperature gradients must be compensated for by proper location of active and compensating gages.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

339. *Mitchell, M.: **Pressure Measurement System for the National Transonic Facility.** Presented at the 29th International Instrumentation Symposium, Albuquerque, New Mex., May 2-6, 1983. In: Proceedings (A85-29551), Research Triangle Park, NC, Instrument Society of America, 1983, pp. 369-381, 6 refs.

A85-29568

The electronically scanned pressure (ESP) measurement system concept was selected for use with the U.S. National Transonic Facility. This pressure measurement application required a complex system design to meet the pressure resolution, range, and accuracy requirements over this tunnel's wide operating pressure and temperature range of 1.38×10^5 to 9.3×10^5 N/m^2 and 80 to 340 K, respectively. The design uses five ESP systems to measure the nearly 1000 channels of pressure located throughout the tunnel circuit. Pressure modules mounted inside the tunnel were housed in specially designed thermal enclosures while the modules mounted outside the tunnel were mounted in pressure vessels. The unique features of this pressure measurement system design, including a special ESP module pressure calibration unit, are presented.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

340. *Gustafson, J. C.: **Control of Large Thermal Distortions in a Cryogenic Wind Tunnel**. JPL 17th Aerospace Mechanisms Symposium, May 1983, pp. 121-142, 3 refs.

N83-24889#

The U.S. National Transonic Facility (NTF) is a research wind tunnel capable of operation at temperatures down to 78 K and pressures up to 880 kPa (8.8 atm) to achieve Reynolds numbers approaching 120 million. Wide temperature excursions combined with the precise alignment requirements of the tunnel aerodynamic surfaces imposed constraints on the mechanisms supporting the internal structures of the tunnel. The material selections suitable for this application were also limited. A general design philosophy of using a single fixed point for each linear degree of freedom and guiding the expansion as required was adopted. These support systems allow thermal expansion to take place in a manner that minimizes the development of thermally induced stresses while maintaining structural alignment and resisting high aerodynamic loads. Typical of the support mechanisms are the preload brackets used in the fan shroud system and the Watts linkage used to support the upstream nacelle. The design of these mechanisms, along with the basic design requirements and the constraints imposed by the tunnel system, are discussed.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

341. *Lynch, F. T.; *Fancher, M. F.; and **Inger, G. R.: **A Theoretical and Experimental Study of Non-Adiabatic Wall Effects on Transonic Shock/Boundary Layer Interaction**. Presented at the AIAA 18th Thermophysics Conference, Montreal, Canada, June 1-3, 1983, 40 pp., 18 refs.

AIAA Paper 83-1421 A83-34901#

Shock-boundary layer interaction can have a significant local and global influence on supercritical transonic viscous flow fields. Questions related to the alteration of interaction effects in connection with surface heat-transfer processes are important in a number of contemporary aerodynamic problems. Included are the immersion of models in the low-temperature nitrogen flow of a transonic cryogenic wind tunnel, cooled turbine blades in hot gas flows, the transonic supercritical flow field around the hot post-reentry Space Shuttle, and aerodynamic surface-heating effects on the magnus moments acting on supercritical projectiles. A study conducted by Inger (1976) suggested even moderate nonadiabatic wall effects could be practically significant in the applications. In the present paper the problem is more extensively studied for a particular type of aerodynamic flow field. Attention is given to the two-dimensional nonseparating transonic flow on a nonadiabatic supercritical airfoil.

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**University of West Virginia, Morgantown, WV 26505 U.S.A.

342. *Bald, W. B.: **A Proposed Method for Model Temperature Conditioning in Cryogenic Wind Tunnels**. OUEL Rept. no. 1480/83, June 1983, 20 pp., 3 refs.

N84-16224#

A technique for precooling models to any desired temperature for cryogenic wind-tunnel tests is proposed. The model is placed in an insulated box with metal liner. Liquid nitrogen is pumped into the container until the temperature is -40 °C. The cavity around the model is filled with Freon 12, giving a uniform model temperature of -30 °C. The liquid nitrogen is connected to an internal cooling loop until the Freon 12 temperature near the bottom of the chamber reaches the desired level. No model distortion due to thermal stresses occur.

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Contract Agreement no. 2057/072-XR/AERO

343. *Stollery, J. L.; and **Stalker, R. J.: **The Development and Use of Free Piston Wind Tunnels**. Presented at the 14th International Symposium on Shock Tubes and Shock Waves held at Sydney, Australia, August 19-22, 1983. In: Proceedings, "Shock Tubes and Waves," 1984, pp. 41-50, 14 refs.

A85-25455

Eggers et al. (1955) have clearly demonstrated the application of free-piston compression in wind-tunnel design. Cox and Winter (1957) developed the gun-tunnel concept and substituted compressed air for explosive powder as the means of driving the piston. The characteristics of free-piston motion are examined, and a comparison between the gun tunnel and shock-tunnel operating cycles is made, taking into account the performance of a number of gun and shock tunnels operating in England. Attention is given to the isentropic 'light' piston tunnels (ILPT's), the cryogenic ILPT, the Stalker tube, and some examples of research in England and Australia using free-piston wind tunnels.

*Cranfield Institute of Technology, Cranfield, Beds MK43 0AL, England
**The Royal Armament Research and Development Establishment, Fort Halstead, Kent TN14 7EU, England

344. *Dor, J.-B.; *Mignosi, A.; and *Plazanet, M.: **Qualification de la Soufflerie T2 en Fonctionnement Cryogenique. (A) Champ Thermique - Etude preliminaire d'une Maquette Schematique. (Certification of the T2 Wind Tunnel During Cryogenic Operation. (A) Temperature Distribution - Preliminary Study of a Schematic Model.)** Rep. DERAT no. 24/5006 DN, August 1983, 112 pp., 12 refs., in French.

Note: For an English translation see citation no. [394] in this bibliography.

This report presents some results from part of the certification tests of the T2 induction tunnel during cryogenic operation. Determination of the transverse temperature distribution in the tunnel under cryogenic test conditions is discussed. Methods and instrumentation used are described.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

345. *Burner, A. W.; and *Goad, W. K.: **Flow Visualization in a Cryogenic Wind Tunnel Using Holography**. Presented at the Third International Symposium, Flow Visualization III, Ann Arbor, Mich., September 6-8, 1983. In: Proceedings, pp. 444-448, 5 refs.

A85-47135

Note: For an earlier form of this paper and an abstract see citation no. [326] in this bibliography.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

346. *Hunter, W. W., Jr.; *Honaker, W. C.; and *Gartrell, L. R.: **Application of Laser Anemometry to Cryogenic Wind Tunnels**. International Congress on Instrumentation in Aerospace Simulation Facilities, ICIASF '83, Saint-Louis, Haut-Rhin, France, September 20, 1983, pp. 200-208, 9 refs.

A84-25226#

The installation and tests made with the laser Doppler and transit anemometer in the NASA Langley 0.3-m Transonic Cryogenic Tunnel are described. Using residual particulates in the flow field, a series of free stream velocity measurements were made which agreed to within 1 percent of predicted values for a range of Mach numbers, 0.2 to 0.85, and temperatures, 100 to 250 K. Measurements about a shock wave gave an estimate of scattering particulate size of 4 microns or less. The particle concentration is approximately 3×10^5 to 1.6×10^6 per m^3. Necessary isolation of the plenum wall windows from ambient air with slightly positive pressure of dry nitrogen gas to prevent condensation on the window surface was achieved. This was done using large enclosures fixed to the tunnel wall. A second method used an additional sheet of thin plate glass to create the dry gas pocket next to the plenum window. The installation of a laser anemometer in the U.S. National Transonic Facility is examined. The laser transit anemometer has been tentatively selected for the initial entry because of its compact laser-optics package.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

347. *McKinney, L. W.: **Operational Experience With the National Transonic Facility**. In: AGARD-CP-348, Wind Tunnels and Testing Techniques (N84-23564#) February 1984, a symposium held at Çesme, Turkey, September 26-29, 1983, pp. 1-1 through 1-8, 10 refs.

N84-23565#

Note: For the complete compilation of papers see citation no. [366] in this bibliography.

Construction of the U.S. National Transonic Facility (NTF) was completed in September 1982. The checkout of all systems required about 1 year. The facility operated to the design point of 120 million Reynolds number based on a 0.25-m chord at a Mach number of 1.0. Performance of all systems was basically as expected. Setup for the detailed aerodynamic calibration begins late in 1983 and the calibration is expected to be complete by the last quarter of 1984.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

348. *North, R. J.; *Maurer, F.; *Prieur, J.; *Schimanski, D.; and *Tizard, J. A.: **The European Transonic Windtunnel (ETW) - Status Report**. In: AGARD-CP-348, Wind Tunnels and Testing Techniques (N84-23564#) February 1984, a symposium held at Çesme, Turkey, September 26-29, 1983, pp. 2-1 through 2-12, 6 refs.

N84-23566#

The status of the preliminary design phase of the European Transonic Windtunnel project is described. The latest version of the proposed tunnel is given together with some details of its estimated performance. Some features of the tunnel which were revised following the first preliminary design proposals are discussed. The results of an investigation into the expected future use of the tunnel are summarized. An aerodynamic circuit test rig is described along with some of the results obtained. Information on the pilot tunnel is included as well as reference to the supporting program on cryogenic technology.

*Technical Group ETW, c/o National Aerospace Laboratory, 1006 BM Amsterdam The Netherlands

349. *Mignosi, A.; and *Dor, J.-B.: **La Soufflerie Cryogenique a Parois Auto-Adaptables T2 de l'ONERA/CERT. The ONERA/CERT T2 Cryogenic Wind Tunnel With Self-Adaptable Walls**. In: AGARD-CP-348, Wind Tunnels and Testing Techniques (N84-23564#) February 1984, a symposium held at Çesme, Turkey, September 26-29, 1983, pp. 3-1 through 3-16, in French. Also: ONERA TP-1983-117, (A84-13630#), 1983, 17 pp., 13 refs., in French.

N84-23567#
or
A84-13630#

The transonic-induction-driven wind tunnel T2 at the ONERA Toulouse Research Center is equipped with a 0.4 × 0.4 m test section. It is a pressurized closed-circuit wind tunnel, operating at ambient temperature with runs of 30 to 60 seconds. The wind tunnel was adapted for cryogenic operation using liquid nitrogen as a coolant and has an internal thermal insulation. The main characteristics of the wind tunnel at low temperature and of the constituents used to perform airfoil tests with adaptive walls are described. The flow qualities are analyzed through an evaluation of the thermal gradients, pressure and thermal fluctuations studies, and the operating limit at very low temperature. The effects of various parameters able to influence test results are examined, such as boundary layer transition and differences between wall temperature and adiabatic wall recovery temperature.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

350. *Viehweger, G.: **The Cryogenic Wind Tunnel Cologne**. In: AGARD-CP-348, Wind Tunnels and Testing Techniques (N84-23564#) February 1984, a symposium held at Çesme, Turkey, September 26-29, 1983, pp. 4-1 through 4-8.

N84-23568#

The modification of a low-speed wind tunnel to cryogenic operation is discussed. The tunnel, with a test section of 2.4 × 2.4 m, should be operational in the middle of 1984. The technical concept of the tunnel is examined and some of the most important components are described.

*DFVLR–Porz-Wahn, Postfach 90 60 58, D-5000 Köln 90 Porz-Wahn, FRG

351. *Chauvet, D.; and **Dujarric, C.: **Production d'une Rafale Cryogenique dans une Soufflerie de Type Eiffel Atmospherique a Rafale Courte. Producing Cryogenic Flows in an Eiffel Type Atmospheric Wind Tunnel With Short Run Time.** In: AGARD-CP-348, Wind Tunnels and Testing Techniques (N84-23564#) February 1984, a symposium held at Çesme, Turkey, September 26-29, 1983, pp. 5-1 through 5-17, 15 refs., in French.

N84-23569#

Demonstrations of the feasibility of an Eiffel-type cryogenic-atmospheric wind tunnel with short run time and of the economy of operation of such a concept requires prior resolution of certain specific technical problems found in this type wind tunnel. The technique for generating cryogenic gaseous flow by atomizing liquid nitrogen in air at the level of the plenum chamber is described as well as the chronological feeding out of a cryogenic gust. Theoretical and experimental studies are developed for optimizing the evaporation of liquid nitrogen in the plenum chamber of a wind tunnel. The results of measuring the size of drops of liquid nitrogen are compared with a computation model which correctly represents the real behavior of the aerosol.

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**Service Technique des Programmes Aeronautiques, 4 avenue de la Porte d'Issy, 75015 Paris, France

352. *Wagner, B.; and *Doker, M.: **Prediction of Condensation Onset and Growth in the European Transonic Windtunnel (ETW).** In: AGARD-CP-348, Wind Tunnels and Testing Techniques (N84-23564#) February 1984, a symposium held at Çesme, Turkey, September 26-29, 1983, pp. 13-1 through 13-11, 17 refs.

N84-23578#

Experimental and theoretical investigations were carried out to allow reliable prediction of condensation onset and growth in cryogenic wind tunnels. The idea of streamline duplication was used in the experiments to simulate European Transonic Windtunnel (ETW) streamlines in an experimental facility of small cross section but with real ETW length scale. Classical nucleation theory was used for developing computer programs which can predict condensation processes in one-dimensional flow including real-gas effects. Experiments and calculations show satisfactory agreement and confirm the possibility of an operating range extension for the ETW. The results provide some new data with respect to those cases where the condensate consists of solid particles.

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**DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

353. *Lynch, F. T.; *Fancher, M. F.; *Patel, D. R.; and **Inger, G. R.: **Nonadiabatic Model Wall Effects on Transonic Airfoil Performance in a Cryogenic Wind Tunnel.** In: AGARD-CP-348, Wind Tunnels and Testing Techniques (N84-23564#) February 1984, a symposium held at Çesme, Turkey, September 26-29, 1983, pp. 14-1 through 14-11, 23 refs.

N84-23579#

This paper addresses the need to match the aircraft surface thermal conditions that exist at in-flight conditions when testing models in a cryogenic wind tunnel. Effects of nonrepresentative heat transfer are reviewed for such basic viscous characteristics as the effect on boundary-layer transition location, the effects on turbulent boundary-layer integral parameters and skin friction, the effect on the transonic turbulent boundary-layer–shock-wave interaction, and the effects on separation onset and the extent of separated flow regions. A complementary experimental and computational study was made to help quantify the impact nonadiabatic model wall conditions would have on the measured aerodynamic characteristics of transport (and other) airplane configurations tested in a cryogenic wind tunnel, and to help establish the allowable deviation from adiabatic wall conditions that can be tolerated if reliable results are to be obtained. Test results are presented which illustrate the large impact of moderate amounts of heat transfer on the lift and drag characteristics for both free-transition flow in the absence of any shock waves and for typical cruise conditions with moderate strength shocks on the airfoil. In addition, test results are shown which illustrate a very large effect of heat transfer on buffet onset conditions and conditions near maximum lift.

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**University of West Virginia, Morgantown, WV 26505 U.S.A.

354. *Griffin, S. A.; *McClain, A. A.; and **Madsen, A. P.: **Design of Advanced Technology Maneuvering Aircraft Models for the National Transonic Facility.** In: AGARD-CP-348, Wind Tunnels and Testing Techniques (N84-23564#) February 1984, a symposium held at Çesme, Turkey, September 26-29, 1983, pp. 25-1 through 25-15, 14 refs.

N84-23590#

The need for a large high-Reynolds-number transonic wind tunnel which will provide a tool to study phenomena sensitive to Reynolds number is discussed. The U.S. National Transonic Facility (NTF) is in the calibration phase and has the desired capability. Its usefulness however, will be influenced by the ability of industry to develop model systems capable of withstanding the severe operating environment of the facility so necessary to achieve full-scale Reynolds number without degradation of accuracy and at reasonable cost. The feasibility of designing models of advanced aerodynamic technology maneuvering aircraft and to achieve full-scale Reynolds number for each configuration in the NTF are determined. It is concluded that the NTF does offer the potential for making tunnel to full-scale data correlations for this type of aircraft configuration.

*General Dynamics, Corp.; Convair Division, P. O. Box 85377, San Diego, CA 92138 U.S.A.
**General Dynamics, Corp.; Fort Worth Division, P. O. Box 748, Fort Worth, TX 76101 U.S.A.

355. *Dotson, E. H.: **Homogeneous Nucleation and Droplet Growth in Nitrogen.** M.S. Thesis, George Washington University, Joint Institute for Advancement of Flight Sciences, September 1983, NASA CR-172206, 88 pp., 16 refs.

N83-34231#

A one-dimensional computer model of the homogeneous nucleation process and growth of condensate for nitrogen flows over airfoils is developed to predict the onset of condensation and thus to be able to take advantage of as much Reynolds number capability of cryogenic tunnels as possible. Homogeneous nucleation data have been taken using a DFVLR CAST-10 airfoil in the NASA Langley 0.3-m Transonic Cryogenic Tunnel and are used to evaluate the classical liquid droplet theory and several proposed corrections to it. For predicting liquid nitrogen condensation effects, use of the arbitrary Tolman constant of 0.25×10^{-10} m or the Reiss or Kikuchi correction agrees with the CAST-10 data. Because no solid nitrogen condensation had been found experimentally during the CAST-10 experiments, earlier nozzle data is used to evaluate corrections to the classical liquid droplet theory in the lower temperature regime. A theoretical expression for the surface tension of solid nitrogen is developed.

*George Washington University, NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
Cooperative Agreement NCC1-44

356. *Tripp, J. S.: **Development of a Distributed-Parameter Mathematical Model for Simulation of Cryogenic Wind Tunnels.** NASA TP-2177, September 1983, 50 pp., 18 refs.

N83-35736#

A one-dimensional distributed-parameter dynamic model of a cryogenic wind tunnel has been developed which accounts for internal and external heat transfer, viscous momentum losses, and slotted-test-section dynamics. Boundary conditions imposed by liquid-nitrogen injection, gas venting, and the tunnel fan have been included. A time-dependent numerical solution to the resultant set of partial differential equations has been obtained on a CDC CYBER 203 vector-processing digital computer at a usable computational rate. Preliminary computational studies were performed by using parameters of the NASA Langley 0.3-m Transonic Cryogenic Tunnel. Studies have been performed by using parameters from the National Transonic Facility (NTF). The NTF wind-tunnel model has been used in the design of control loops for Mach number, total temperature and total pressure, and for determining interactions between the control loops. It has been employed in the application of optimal linear-regulator theory and eigenvalue-placement techniques to develop Mach number control laws.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

357. *Dor, J.-B.; *Mignosi, A.; and *Plazanet, M.: **Qualification de la Soufflerie T2 en Fonctionement Cryogenique. (B). Fluctuations de l'Ecoulement–Detection et Qualification de Particules. (B). Fluctuations in the Flow-Detection of Particles in Cryogenic Flow and Apparatus Used for a Qualitative Study.)** Rept. DERAT no. 25/5006 DN, September 1983, 81 pp., 13 refs., in French.

Note: For an English translation see citation no. [395] in this bibliography.

Some results are presented of the certification tests of the T2 transonic-induction tunnel during its operation at cryogenic temperatures. The first part gives results concerning pressure and temperature in both ambient and cryogenic regimes. The second part shows the phenomena of condensation in cryogenic flow using an optical system of detecting particles.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

358. *Mignosi, A.: **Cryogenic Methods in Wind Tunnels.** Paper presented at the Association Aeronautique et Astronautique de France, 20th Colloque d'Aerodynamique Appliquee, Toulouse, France, November 8-10, 1983, 31 pp., in French.

AAAF Paper NT 83-08 A84-32479

This paper surveys current progress in the application of low-temperature techniques to achieve flightlike Reynolds numbers in wind tunnels. It reviews the basic principles of cryogenic wind-tunnel operation and the associated boundary layer, transition, flow quality, and condensation limit problems. The technology and instrumentation used in the various facilities (NTF, ETW, KKK, T2, PETW) are discussed and illustrated with diagrams.
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359. *Kilgore, R. A.; *Dress, D. A.; and *Lawing, P. L.: **Some of the Capabilities and Desirable Features of an "Ideal" Transonic Wind Tunnel.** NASA TM-85484, November 1983, 23 pp., 13 refs.

N84-72329

Personnel of the Experimental Techniques Branch were asked to make a contribution to the definition of an ideal transonic tunnel in a survey being conducted under the auspices of the Ground Testing Technical Committee of the American Institute of Aeronautics and Astronautics (AIAA). The purpose of this paper is to document the response of the Branch to that survey. Based on many conflicting requirements, the "consensus ideal" transonic tunnel would have a 2.5×2.5 m test section, operate at pressures from about 0.5 to 5.0 atm, temperatures from about 77.4 to 340 K, and cover the range of Mach numbers from about 0.02 to 1.30. The maximum Reynolds number at sonic speeds would be about 50 million based on a reference dimension of 0.25 m. Desirable features would include a water-air heat exchanger for ambient temperature operation, an adjustable second minimum, an adaptive-wall test section (solid walls), and a magnetic suspension and balance system.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

360. *Nelander, C.: **A Quasi-Continuous Transonic Wind Tunnel for Cryogenic Operation.** ROLLAB-Memo-RM-096, November 1983, 13 pp.

N84-15161#

An alternative for driving a transonic or subsonic facility of medium to large size is described. The principle is to drive the fan in a closed-circuit tunnel using an air turbine fed by a high-pressure air storage. The temperature rise imposed by the fan will be taken care of by introducing the cold outlet air from the turbine into the tunnel circuit. The same amount of air will be dumped to the atmosphere via a heat exchanger or matrix, thus cooling down the high-pressure air. The stagnation enthalpy in the tunnel will be the same as the enthalpy of the driving gas in front of the turbine and the regeneration of the matrix accomplished by the temperature difference due to the Joule-Thomson effect.

*Aktiebolaget Rollab, Jarvstigen 5, Box 7073, S-171 07 Solna, Sweden

361. *Portat, M.; and *Helias, F.: **Characterization of Pressure Transducers for Future Cryogenic Wind Tunnels.** In ESA-TT-841, English edition of La Recherche Aerospatiale, Bimonthly Bulletin no. 1983-6, November-December, 1983, pp. 35-40.

N84-25873#

Operating cryogenic wind tunnels will require measurement equipment adapted to the specific environmental conditions. Among other things, it must be known how the existing wind-tunnel pressure transducers will behave in a cryogenic environment. To this end, ONERA has developed special instruments to measure pressure transducer characteristics accurately between 300 and 120 K. Static tests carried out on the Kulite XCQL and ONERA 20H130 transducers show they are usable at 120 K.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

362. *Boyden, R. P.; *Johnson, W. G., Jr.; and *Ferris, A. T.: **Aerodynamic Force Measurements With a Strain-Gage Balance in a Cryogenic Wind Tunnel.** NASA TP-2251, December 1983, 42 pp., 12 refs.

N84-13162#

Aerodynamic force measurements on a generalized 75° delta-wing model with sharp leading edges have been made with a three-component internal strain-gage balance in a cryogenic wind tunnel at stagnation temperatures of 300, 200, and 110 K. The feasibility of using a strain-gage balance without thermal control in a cryogenic environment as well as the use of electrical resistance heaters, an insulator between the model and the balance, and a convection shield on the balance was studied. Force and moment data on the delta-wing model as measured by the balance are compared at the different temperatures while holding constant either the Reynolds number or the tunnel stagnation pressure. Tests were made at Mach numbers of 0.3 and 0.5 and at angles of attack up to 29°. The results show it is feasible to acquire accurate force and moment data while operating at steady-state thermal conditions in a cryogenic wind tunnel, either with or without electrical heaters on the balance. Within the limits of the balance accuracy, there were no apparent Reynolds number effects on the aerodynamic results for the delta-wing model.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

363. *Schoenmakers, T. J.; and *Baljeu, J. F.: **Development of a Non-Insulated Cryogenic Strain-Gauge Balance. Estimate of the Accuracy of Balance No. 771 at Temperatures Between 90 K and 300 K.** NLR-National Aerospace Lab., Amsterdam, TP-82-005-U, 1983, 9 pp.

N83-26045#

The influence of the combination of loads acting on it, the temperature, and the temperature gradients on a three-component cryogenic balance was studied. The effect of combined loads is determined at room temperature and is taken into account by means of a second order calibration. The temperature effects give rise to the application of four corrections on the test data. The estimated accuracy of the cryogenic balance presented is the summation of the accuracy with which the corrections were determined. The measurement of aerodynamic drag appears to be considerably less accurate than the measurement of the lift and pitching moment, mainly due to the influence of temperature gradients.

*National Aerospace Laboratory, 1006 BM Amsterdam, The Netherlands

364. *Alekseyev, L. P.; and *Fuks, M. A.: **(A Cryogenic Wind Tunnel.)** In: Trudy Giproniiaviaprom (USSR), no. 19, 1983, pp. 13-22, in Russian.

Note: For an English translation of this paper, see citation no. [427] in this bibliography.

*Central Aero-Hydrodynamic Institute (TsAGI), U.S.S.R.

365. *Hall, R. M.: **Pre-existing Seed Particles and the Onset of Condensation in Cryogenic Wind Tunnels.** Presented at the AIAA 22nd Aerospace Sciences Meeting, Reno, Nevada, January 9-12, 1984, 9 pp., 10 refs.

AIAA Paper 84-0244 A84-17972#

The condensation research at NASA Langley Research Center has used a variety of experimental approaches to gather information on seed particles that can act as sites for condensation growth. Total-pressure measurements have suggested condensation growth is caused by impurities in the flow and not by unevaporated liquid nitrogen (LN_2) injected to cool the 0.3-m Transonic Cryogenic Tunnel. A separate test with an optical droplet sizing probe, designed to detect droplets in the 2- to 300-micron range, confirmed the conclusions from the total-pressure measurements and also discovered what appears to be solidified oil droplets having diameters of about 3 microns. These oil droplets appear to be the dominant source of seed particles above 2 microns. However, computer simulations of static pressure test data suggest that the measured condensation effects are the result of more numerous, smaller seeds with number densities on the order of 10^{12} per kilogram of the gas and diameters on the order of 0.5 microns.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

366. *AGARD: **Wind Tunnels and Testing Techniques.** Fluid Dynamics Panel Symposium on Wind Tunnels and Testing Techniques, Çesme, Turkey, September 26-29, 1983, AGARD-CP-348, February 1984, 514 pp.

ISBN-92-835-0348-1 N84-23564#

Note: Thirty-six papers are contained in this volume. Papers pertinent to cryogenic wind tunnels are listed separately under the date of presentation (September 26-29, 1983), citation nos. [347 through 354] in this bibliography.

The design and operation of cryogenic wind tunnels and transonic facilities are discussed as well as associated fluid-motion problems. Testing techniques are considered with emphasis on support interference, inlet/engine/afterbodies, store separation, half models, aeroacoustic measurements, and wind-tunnel flight-data comparisons.

*AGARD (Advisory Group for Aerospace R&D), NATO, 7 Rue Ancelle, 92200 Neuilly-sur-Seine, France

367. *Bruce, W. E., Jr.; *Fuller, D. E.; and *Igoe, W. B.: **National Transonic Facility Shakedown Test Results and Calibration Plan.** Presented at the AIAA 13th Aerodynamic Testing Conference, San Diego, Calif., March 5-7, 1984, Technical Papers, 13 pp., 12 refs.

AIAA Paper 84-0584 A85-16101#

The construction of the U. S. National Transonic Facility (NTF) was completed in September 1982 and shakedown operations started the following month, with the maximum Reynolds number being obtained in May 1983. Since then, most of the effort has been devoted to installing the model-access housings and adjusting or altering various tunnel components. The current ongoing effort is devoted to checking out the model attitude, plenum isolation, and model access systems. Upon completion of this, the aerodynamic calibration will follow. The facility has been operated in both air and nitrogen modes covering a Mach number range of 0.2 to 1.17 at pressures up to 8.5 atm and at temperatures down to 100 K. A limited amount of performance information was obtained during shakedown and is presented in this paper along with an outline of the calibration plans for the tunnel.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

368. *Gloss, B. B.: **Initial Research Program for the National Transonic Facility.** Presented at the AIAA 13th Aerodynamic Testing Conference, San Diego, Calif., March 5-7, 1984, Technical Papers, pp. 1-11, 42 refs.

AIAA Paper 84-0585 A84-24177#

The construction and checkout of the U.S. National Transonic Facility (NTF) have been completed and detailed calibration is now in progress. The initial NTF research program covers a wide range of study areas falling into three major elements: (1) the assessment of Reynolds number sensitivities for a broad range of configurations and flow phenomena, (2) validation of the ability of NTF to simulate full-scale aerodynamics, and (3) the development of test techniques for improved test simulations in existing wind tunnels. This paper is a status report on these various elements of the initial NTF research program.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

369. *Young, C. P., Jr.; *Bradshaw, J. F.; *Rush, H. F., Jr.; *Wallace, J. W.; and *Watkins, V. E., Jr.: **Cryogenic Wind-Tunnel Model Technology Development Activities at the NASA Langley Research Center.** AIAA 13th Aerodynamic Testing Conference, San Diego, Calif., Technical Papers, March 5-7, 1984, pp. 12-29, 27 refs.

AIAA Paper 84-0586 A84-24178#

This paper summarizes the current cryogenic wind-tunnel model technology development activities at the NASA Langley Research Center. These research and development activities are being made in support of the design and building of models for the new U.S. National Transonic Facility (NTF). The scope and current status of major research and development work is described and data is presented from various studies. In addition, design and fabrication experience for existing developmental models to be tested in the NTF are discussed.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

370. *Johnson, C. B.; and *Stainback, P. C.: **A Study of Dynamic Measurements Made in the Settling Chamber of the Langley 0.3-m Transonic Cryogenic Tunnel.** AIAA 13th Aerodynamic Testing Conference, San Diego, Calif., March 5-7, 1984, Technical Papers, pp. 109-119, 10 refs.

AIAA Paper 84-0596 A84-24186#

Tests have been made in a cryogenic wind-tunnel settling chamber using fast response instrumentation to measure the possible existence of temperature fronts due to a sudden or step change in the rate of liquid nitrogen injection into the circuit. No indications of such fronts were obtained using three different techniques to change the rate of nitrogen injection. The normalized pressure and velocity fluctuations at two total temperatures and over a large range of Mach numbers and Reynolds numbers were about 2×10^{-7} to 2×10^{-6} and about 1.8 to 3 percent, respectively. There was no evidence of liquid nitrogen droplets in the flow down to a total temperature of 140 K. The pressure fluctuation power spectra from a pressure transducer correlated with the fan-blade passage through the eighth harmonic.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

371. *Sawada, H.: **NAL TCWT Status - Cryogenic Operation,** NAL News, no. 229, March 1984, pp. 2-4, in Japanese.

ISSN 0023-2726

This paper describes the 0.1 × 0.1 m Transonic Cryogenic Wind Tunnel at the National Aerospace Laboratory (NAL). It also describes the use of the original manual control systems for typical purging, cooldown, running, and warm-up operations.

*National Aerospace Laboratory, 7-44-1 Jindaiji-machi Chofu-shi, Tokyo 182, Japan

372. *Christophe, J.; *Bazin, M.; *Broussaud, P.; *Francois, G.; *Paci, P.; and *Dubois, M.: **Developments in Research Stimulated by Cryogenic Wind Tunnel Construction Planning and Projects.** La Recherche Aerospatiale (English edition), no. 2, March-April 1984, pp. 25-44, 45 refs.

ISSN-0379-380X A84-46764#

Recent developments in cryogenic wind-tunnel research are briefly summarized. Particular emphasis is given to work being performed by ONERA in the effort to design transonic wind tunnels with high Reynolds numbers. Some technical considerations in the design of the European Transonic Windtunnel are discussed, including wind-tunnel insulation, the use of alternative gases such as nitrogen, and the properties of materials to be used in the building of wind-tunnel models. Consideration is also given to the design and building of model precooling and injection devices.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

373. *Michel, R.; and *Mignosi, A.: **First Cryogenic Tests of an Airfoil in ONERA/CERT T2 Wind Tunnel.** La Recherche Aerospatiale (English edition), no. 2, March-April 1984, pp. 69-71, 2 refs.

ISSN-0379-380X A84-46767#

The adaptation of the transonic T2 induction-driven wind tunnel at ONERA/CERT for operation at low temperatures has required internal thermal insulation through the entire circuit. To cool the flow, a liquid nitrogen injection device has been installed. Before entering the operational phase of studies on models in cryogenic flow, the cryogenic operation of the wind tunnel was maximized through the study of the establishment and stabilization of temperature, the qualification of flow qualities, and the preparation of a preliminary operation to cool the models. Current studies involve tests of a CAST 7 airfoil at different pressures and temperatures, and the determination of its aerodynamic characteristics through a range of Reynolds numbers. Two aspects are presented for the test technique: use of a gaseous nitrogen cooling device and the use of adaptive walls which are formed to simulate boundary conditions very close to those of an infinite flow field. An initial cryogenic test program has been run on the CAST 7 airfoil. Some results used to confirm temperature test validity conditions are presented along with a definition of the variation of lift with the Reynolds number.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

374. *Germain, E. F.; and *Compton, E. C.: **Evaluation Tests of Platinum Resistance Thermometers for a Cryogenic Wind Tunnel Application.** NASA TM-85803, April 1984, 16 pp., 6 refs.

N84-23865#

Thirty-one commercially designed platinum resistance thermometers were evaluated for applicability to stagnation temperature measurements between -190 °C and 65 °C in the U.S. National Transonic Facility. Evaluation tests included x-ray shadowgraphs, calibrations before and after aging, and time constant measurements. Two wire-wound low-thermal-mass probes of a conventional design were chosen as most suitable for this cryogenic wind-tunnel application.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

375. *Daryabeigi, K.; and *Ash, R. L.: **NTF Stagnation Temperature Measurements. Final Report, 1 June 1983 - 15 January 1984.** NASA CR-173380, April 1984, 39 pp., 12 refs.

N84-73576

The accuracy of the U.S. National Transonic Facility (NTF) stagnation temperature measurement system was studied. Issues addressed included the accuracy of a simplified calibration approximation of the 1968 International Practical Temperature Scale for platinum resistance thermometers (used in this system), and the accuracy of the supporting instrumentation. In addition, the conduction error for the platinum resistance thermometer configuration used in the NTF was studied. This analysis shows the NTF stagnation temperature measurement system can be accurate to within ±0.06 K over the interval $126.15 \text{ K} \leq T \leq 363.15 \text{ K}$.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.

376. *Mignosi, A.; and *Imbert, R.: **First Cryogenic Test of the CAST 7 Profile in the T2 Wind Tunnel. Comparison with Calculations.** (Premiers essais cryogeniques du profil CAST 7 à la soufflerie T2. Comparaisons avec les calculs.) (ONERA-RTS-58/1685-AY-035-D), April 1984, 66 pp., 10 refs., in French.

N85-13682#

The influence of Reynolds number at a Mach number of 0.76 was studied in natural and enhanced transition using a CAST 7 airfoil with a 150 mm chord. The wind tunnel and the experimental technique are described. Studies on wall choice and on the thermal equilibrium of the model are included. Computations solving the transonic potential equation with inclusion of viscous effects are presented. Important differences between experiment and theory are observed.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

377. *Kilgore, R. A.: **Cryogenic Wind Tunnels for High Reynolds Number Testing.** Lecture presented at the University of Tennessee Space Institute Short Course on Aerospace Ground Test Facilities and Flight Testing, Tullahoma, Tenn., May 8, 1984, 63 pp. (An enlarged, updated version of previous presentations.)

A84-42900#

This lecture gives an overview of the evolution and early development of cryogenic wind tunnels. It also gives a status report on some of the cryogenic wind-tunnel activities around the world. Finally, it provides a brief look at some developments aimed at further improving the testing capabilities of wind tunnels.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

378. *Domack, M. S.: **Fracture Temperature and Flow Growth in Nitronic 40 at Cryogenic Temperatures.** NASA TP-2312, May 1984, 46 pp., 16 refs.

N84-23750#

The fracture resistance and fatigue response of Armco Nitronic 40 austenitic stainless steel were evaluated under cryogenic conditions. Tensile, fracture toughness, and fatigue crack growth properties were measured at -275 F. The tensile yield strength was approximately 120 ksi and the fracture toughness was estimated to be 350 ksi-in /2 on the basis of fracture toughness measurements. Testing was conducted to evaluate the behavior of a simulated section of the wing of the Pathfinder I model subject to a load and temperature history typical of that for testing in the National Transonic Facility. The wing-section model incorporated a proposed brazing technique for pressure-transducer attachment. The simulated wing section performed satisfactorily at stress levels of nearly 60 percent of the material yield strength. The brazing technique proved to be an effective method of transducer attachment under conditions of high-stress levels and large temperature excersions.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

379. *Beck, J. W.: **Cryogenic Wind Tunnel Technology - A Way to Measurement at Higher Reynolds Numbers.** NASA TM-77481, May 1984, 34 pp. Translation from "Kryo-Windkanal-Technologie: Ein Weg zur Messung bei Hoeheren Reynolds-Zahlen," Munich (A83-46484), February 1, 1982, pp. 53-81, 83-37, 11 refs.

N84-34451#

Note: For the original German form see citation no. [267] in this bibliography.

The goals, design, problems, and value of cryogenic transonic wind tunnels being developed in Europe are discussed. The disadvantages inherent in low-Reynolds number wind-tunnel simulations of aircraft flight at high Reynolds number are reviewed, and the cryogenic tunnel is shown to be the most practical method to achieve high Reynolds number. The design proposed for the European Transonic Windtunnel (ETW) is presented: parameters include test section = 4 sq m, operating pressure = 5 bar, temperature = 110 to 120 K, maximum Re = 40 million, liquid N_2 consumption = 40,000 metric tons/year, and power = 39.5 MW. The DFVLR-Köln subsonic tunnel being adapted to cryogenic use for preliminary studies is described. Problems of configuration, materials, and liquid N_2 evaporation and handling the research underway to solve them are outlined. The benefits to be gained by the construction of these costly wind tunnels are seen more in applied aerodynamics than in basic research in fluid physics. The need for parallel development of both high-Reynolds-number tunnels and computers capable of performing high-Reynolds-number numerical analysis is stressed.

*DFVLR–Wessling/Obb., Oberpfaffenhofen, D-8031 Wessling/Obb., FRG

380. *Elsenaar, A.: **Technical Evaluation Report on the Fluid Dynamics Panel Symposium on Wind Tunnels and Testing Techniques.** AGARD-AR-193, May 1984, 13 pp. Symposium held in Çesme, Turkey, September 26-29, 1983.

ISBN-92-835-1473-4 N84-32402#

The first section of the evaluation report is devoted to the history of cryogenic testing. Continuous and intermittent cryogenic facilities are described. Model design and aerodynamic aspects are discussed.

*National Aerospace Laboratory, 1006 BM Amsterdam, The Netherlands

381. *Carlson, A. B.: **Thermal Analysis of Cryogenic Wind Tunnel Models.** AIAA 19th Thermophysics Conference, Snowmass, Colo., June 25-28, 1984, 9 pp., 10 refs.

AIAA Paper 84-1802 A84-37516#

This paper summarizes the thermal analysis activity being made in support of the design of wind-tunnel models for the U.S. National Transonic Facility (NTF) at the NASA Langley Research Center. The goal of the analysis effort has been to address model design difficulties associated with the severe thermal environment of this cryogenic wind tunnel. The unique characteristics of this environment are discussed for various phases of tunnel operation. The methods used to calculate temperatures and thermal stresses in the models are also described. The results show that thermal considerations do not drive the design to the extent originally envisioned. In general, the problems identified are localized and associated with thermal mismatch between components. Several specific examples of thermal design problems and proposed solutions are given.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

382. *Graewe, E.: **Development of a 6-Component Balance for the Cryogenic Range. Final Report, April 1983.** DCAF E002631. Rep. no. BMFT-IB-W-84-022, June 1984, 51 pp., 6 refs.

ISSN-0170-1339 N84-30270#

Criteria for wind-tunnel strain-gage balances applicable in the temperature range 100 to 300 K were derived. An unheated six-component balance was built and examined. With the corresponding software, this balance is practicable on quasi-stationary temperatures in the range 100 to 300 K.

*Messerschmitt-Bölkow-Blohm GmbH–Bremen, Postfach 107845, D-2800 Bremen 1, FRG

383. *Pan, R.: **A Cryogenic High-Reynolds Number Transonic Wind Tunnel with Pre-Cooled and Restricted Flow.** Acta Aerodynamica Sinica (China Aerodynamics Research Society) no. 2, June 1984, pp. 87-92, in Chinese.

A85-35752#

Note: For an English translation and an abstract see citation no. [439] in this bibliography.

*China Aerodynamic Research and Development Center (CARDC), P. O. Box 211, Mianyang, Sichuan, China

384. *Campbell, J. F.: **The National Transonic Facility - A Research Perspective**. Paper presented at the AIAA 2nd Applied Aerodynamics Conference, Seattle, Wash., August 21-23, 1984, 17 pp., 45 refs.

AIAA Paper 84-2150 A84-44189#

The status of the calibration, correlation, and research efforts of the U.S. National Transonic Facility (NTF) is presented. The research program is reviewed in more detail, citing aerodynamic problem areas, research needs, and the accompanying NTF program which addresses some of these needs. The description of the research program is broken into four categories: basic fluid mechanics, transport aircraft aerodynamics, fighter aircraft aerodynamics, and computational fluid dynamics.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

385. *Goodyer, M. J.: **Engineering Changes to the 0.1 m Cryogenic Wind Tunnel at Southampton University.** NASA CR-172430, August 1984, 20 pp., 4 refs.

N84-32397

This report outlines the more important changes to the tunnel since its completion in 1977. These include detailed improvements in the fan drive to allow higher speeds and the provision for a test section leg suitable for use with a magnetic suspension and balance system. The instrumentation, data logging, data reduction, and tunnel controls have also been improved and modernized. The report concludes with a tunnel performance summary.

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Contract NAS1-16000

386. *Wallace, J. W.: **Fastener Load Tests and Retention Systems Tests for Cryogenic Wind-Tunnel Models.** NASA TM-85805, August 1984, 46 pp., 3 refs.

N84-28964#

This paper presents the results of a fastener load and retention systems test program, carried out as a part of the cryogenic models technology development activities at the NASA Langley Research Center. A-286 stainless steel screws were tested to determine the tensile load capability and failure mode of various screw sizes and types at both cryogenic and room temperatures. Additionally, five fastener retention systems were tested by using A-286 screws with specimens made from the primary metallic alloys used for cryogenic models. The locking-system effectiveness was examined by simple no-load cycling to cryogenic temperatures (-275 °F) as well as by dynamic and static loading at cryogenic temperatures. In general, most systems were found to be effective retention devices. There are some differences between the various devices with respect to ease of application, cleanup, and reuse. Also, results of tests at -275 °F imply that the cold temperatures act to improve screw retention. The improved retention is probably the result of differential thermal contraction and/or increased friction (thread--binding effects). The data in this paper is provided for use in selecting screw sizes, types, and locking devices for model systems to be tested in cryogenic wind tunnels.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

387. *Kilgore, R. A.; and *Dress, D. A.: **The Application of Cryogenics to High Reynolds Number Testing in Wind Tunnels. Part 1: Evolution, Theory, and Advantages.** Cryogenics, vol. 24, no. 8, August 1984, pp. 395-402, 30 refs.

ISSN-0011-2275 A85-41328

During the time since the construction of the first wind tunnel in 1870, wind tunnels have been developed to a high degree of sophistication. However, their development has consistently failed to keep pace with the demands placed on them. One of the more serious problems with existing transonic wind tunnels is their inability to test subscale aircraft models at Reynolds numbers sufficiently near full-scale values to ensure the validity of using the wind-tunnel data to predict flight characteristics. The Reynolds number capability of a wind tunnel may be increased by a number of different approaches. However, the best solution in terms of model, balance, and model support loads, as well as in terms of capital and operating cost, is to reduce the temperature of the test gas to cryogenic temperatures. This paper reviews the evolution of the cryogenic wind-tunnel concept and describes its more important advantages.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

388. *Kilgore, R. A.; and *Dress, D. A.: **The Application of Cryogenics to High Reynolds Number Testing in Wind Tunnels. Part 2: Development and Application of the Cryogenic Wind Tunnel Concept.** Cryogenics, vol. 24, no. 9, September 1984, pp. 484-493, 34 refs.

ISSN-0011-2275

An improved way to increase the Reynolds number capability of wind tunnels has been developed through the application of cryogenic technology. Part 1 of this two-part review covered the evolution, theory, and major advantages of cryogenic wind tunnels. This paper describes the development and early application of the cryogenic wind-tunnel concept in the United States at the NASA Langley Research Center. Also presented are some of the major activities around the world related to cryogenic wind tunnels. The most significant of these is the U.S. National Transonic Facility (NTF), a large transonic cryogenic tunnel recently completed at the NASA Langley Research Center.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

389. *Viehweger, G.: **The Kryo-Kanal Köln (KKK) as an Example of a Higher-Reynolds-Number Wind Tunnel.** (Windkanäle höherer Reynoldszahlen am Beispiel des Kryo-Kanal-Köln/KKK/). Presented at the annual meeting of the German Aeronautical and Astronautical Society in Hamburg, Germany, October 1-3, 1984, 25 pp., 13 refs.

DGLR Paper 84-095 A85-40314#

The fundamental principles, costs, and operational phases (cooldown, preparation, starting, measurement, rundown, and warming) of cryogenic wind tunnels are discussed. The problems encountered in modifying the conventional low-speed wind tunnel at Köln for cryogenic operation are discussed. Particular attention is given to the test section, the fan section, the liquid-N_2 system, the exhaust and safety system, and the interior insulation. Photographs, drawings, and diagrams are provided. The first trial operation of the KKK took place in September 1984, with calibration under cryogenic conditions scheduled for the second half of 1985.

*DFVLR–Porz-Wahn, Postfach 90 60 58, D-5000 Köln 90 Porz-Wahn, FRG

390. *Firth, G. C.; and *Watkins, V. E., Jr.: **Investigation of Low-Temperature Solders for Cryogenic Wind Tunnel Models.** Presented at the symposium held at NASA Langley Research Center in Hampton, Va., October 23-25, 1984. In: NASA CP-2387, "Welding, Bonding, and Fastening", N86-11227, September 1985, pp. 21-34, 5 refs.

N86-11230#

The advent of high-Reynolds-number cryogenic wind tunnels has forced alteration of manufacturing and assembly techniques and eliminated usage of many materials associated with conventional wind-tunnel models. One of the techniques affected is soldering. Solder alloys commonly used for wind-tunnel models are susceptible to low-temperature embrittlement and phase transformation. The low-temperature performance of several solder alloys is being examined during research and development activities in support of design and fabrication of cryogenic wind-tunnel models. Among the properties examined during these tests are shear strength, surface quality, joint stability, and durability when subjected to dynamic loading. Results of these tests and experiences with recent models are summarized.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

391. *Hall, E. T., Jr.: **NTF: Soldering Technology Development for Cryogenics.** Presented at the symposium held at NASA Langley Research Center in Hampton, Va., October 23-25, 1984. In: NASA CP-2387, September 1985, "Welding, Bonding, and Fastening", N86-11227, pp. 35-54, 2 refs.

N86-11231#

The advent of the U.S. National Transonic Facility (NTF) brought about a new application for an old joining method, soldering. Soldering for use at cryogenic temperatures requires solders that remain ductile and free from tin-pest (grey tin), have toughness to withstand aerodynamic loads associated with flight research, and maintain their surface finishes. Solders are used to attach 347 Stainless-Steel tubing in surface grooves of models. The solder must fill up the gap and metallurgically bond to the tubing and model. Cryogenic temperatures require that only specific materials for models be used, including the following: Vasco Max 200 CVM, Lescalloy A-286 Vac Arc, and pH 13-8 Mo. Solders identified for testing at this time are 50% Sn - 49.5% Pb - 0.5% Sb, 95% Sn - 5% Sb, 50% In 50% Pb, and 37.5% Sn - 37.5% Pb - 25% In. With these materials and solders, it is necessary to determine their solderability. After solderability is determined, tube/groove specimens are fabricated and stressed under cryogenic temperatures. Compatible solders are then used for actual models.

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392. *Firth, G. C.: **Initial Investigation of Cryogenic Wind Tunnel Model Filler Materials.** Presented at the symposium held at NASA Langley Research Center in Hampton, Va., October 23-25, 1984. In: NASA CP-2387, September 1985, "Welding, Bonding, and Fastening", N86-11227, pp. 465-481, 4 refs.

N86-11255#

Filler materials are used for surface flaws, instrumentation grooves, and fastener holes in wind-tunnel models. More stringent surface-quality requirements and the more demanding test environment in cryogenic wind tunnels eliminate filler materials such as polyester resins, plaster, and waxes used on conventional wind-tunnel models. To provide a material data base for cryogenic models, various filler materials are studied. Surface-quality requirements and test-temperature extremes require matching of coefficients of thermal expansion of interfacing materials. Microstrain versus temperature curves are generated for several candidate filler materials for comparison with cryogenically-acceptable materials. Matches have been achieved for aluminum alloys and austenitic steels. Simulated model surfaces are filled with candidate filler materials to determine finishing characteristics, adhesion, and stability when subjected to cryogenic cycling. Filler material systems are identified which meet requirements for use with aluminum models.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

393. *Dress, D. A.; *Lawing, P. L.; and *Kilgore, R. A.: **An External Insulation System for a Cryogenic Wind Tunnel.** Presented at the 5th Intersociety Cryogenics Symposium, New Orleans, La., sponsored by IIR, ASME, and AIChE, December 9-14, 1984, 8 pp., 13 refs.

A85-41340#

The thermal insulation system of the 0.3-meter Transonic Cryogenic Tunnel (0.3-m TCT) at the NASA Langley Research Center is described in text, photographs, and drawings. The system is designed to operate from room temperature down to about 77.4 K, the temperature of liquid nitrogen at 1 atm. A detailed description is given of the primary insulation system which consists of glass fiber mats, a 3-part vapor barrier, and a dry nitrogen positive-pressure purge system. Also described are several secondary insulation systems required for the test section, actuators, and tunnel supports. An appendix briefly describes the original insulation system considered inferior to the one presently in place. Time required for opening and closing portions of the insulation system for modification or repair to the tunnel has been reduced, typically from a few days for the original thermal insulating system to a few hours for the present system.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

394. *Dor, J.-B.; *Mignosi, A.; and *Plazanet, M.: **Qualification of the T2 Wind Tunnel in Cryogenic Operation. A: Thermal Field - Preliminary Study of a Schematic Model.** A translation by the Corporate Word, Pittsburgh, Pa. of "Qualification de la Soufflerie T2 en Fonctionnement Cryogenique. A) Champ Thermique - Etude Preliminaire d'une Maquett Schematique." ONERA/CERT, Toulouse, France. Technical Report OA 24/5006 (DERAT 24/5006 DN), August 1983, pp. 1-52. NASA TM-77781, December 1984, 117 pp., 12 refs.

N85-23805#

Note: For the original French paper, see citation no. [344] in this bibliography.

The T2 wind tunnel is described. The process of generating an intermittent cryogenic flow using the data from a test made at very low temperature is presented. Detailed results of test on temperatures for flow in the settling chamber, the interior walls of the system, and the metal casing are given. The transverse temperature distribution in the settling chamber and test section, and of the thermal gradients in the walls, is given as a function of the temperature level of the test.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France
Contract NASw-4006 (for translation)

395. *Dor, J.-B.; *Mignosi, A.; and *Plazanet, M.: **Qualification of the T2 Wind Tunnel in Cryogenic Operation. B: Flow Fluctuation - Particle Detection and Qualification.** A translation by the Corporate Word, Pittsburgh, Pa., of "Qualification de al soufflerie T2 en fonctionnement cryogenique. B. Fluctuations de l'Ecoulement - Detection et Qualification de Particules." ONERA/CERT, Toulouse, France, Technical Report OA no. 25/5006, (DERAT no. 25/5006 DN), September 1983, pp. 1-39. NASA TM-77782, December 1984, 84 pp., 13 refs.

N85-23806#

Note: For the French paper, see citation no. [357] in this bibliography.

This report presents part of the tests for verification of the T2 transonic-induction wind tunnel in cryogenic operation. The first part of the results presented concerns fluctuations in pressure and temperature at ambient and cryogenic temperatures. The second part presents the condensation phenomena which could be observed in the cryogenic flow by means of an optical particle detection system in the test section.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

396. **AIAA 13th Aerodynamic Testing Conference - Technical Papers**, 1984, (A84-24177-A84-24210), 346 pp., Conference held in San Diego, Calif., March 5-7, 1984, 346 pp.

TL570.A32/1984 A84-24176

Various topics on aerodynamic testing are addressed. The subjects considered include the following: aeropropulsion systems test facility, real-time engine testing, transport configuration wind-tunnel test with engine simulation, civil turbofan propulsion system integration studies using powered testing techniques, dynamic measurements in the settling chamber of a transonic cryogenic tunnel, aerodynamic and propulsion test unit with vitiated air heater, and subscale testing of an ice suppression system for Space Shuttle launches. Also discussed are dynamic flow-quality measurements in a low-turbulence pressure tunnel, data acquisition and reduction techniques for a solar collector pressure test, application of adaptive wall to high-lift subsonic aerodynamic testing, wind-tunnel tests on a high-performance low-Reynolds-number airfoil, development and calibration of miniature Mach-flow-angularity probes, pressure records analysis in an unsteady expansion wave, and a new concept for exhaust diffusers of altitude test cells.

Note: Several papers of possible interest to the users of this bibliography are listed under the date of presentation, see citation nos. [367 through 370] in this bibliography.

397. *Vorburger, T. V.; *McLay, M. J.; *Scire, F. E.; *Gilsinn, D. E.; and *Giauque, C. H. W.: **Surface Roughness Studies for Wind Tunnel Models Used in High Reynolds Number Testing.** Presented at the AIAA 23rd Aerospace Sciences Meeting, Reno, Nev., January 14-17, 1985. Also, Journal of Aircraft, vol. 23, January 1986, pp. 56-61, 31 refs.

AIAA Paper 85-0228 A86-20161#

Note: For later version of this paper see citation no. [442] in this bibliography.

This paper focuses on stylus and optical techniques for the measurement of surface roughness in wind-tunnel models. The stylus instruments provide detailed information, such as surface profiles and area maps, that may be used either to calculate statistical properties (e.g., the rms surface roughness) or to study individual surface peaks or other features. By contrast, certain optical techniques yield area-averaged statistical properties of the surface roughness directly. Two instruments that use the technique of optical angular scattering are compared. One is a research instrument developed to study the basic scattering phenomena by testing the optical theories and surface models used in inverse calculations of statistical roughness parameters. The second instrument is more compact and is under development as a hand held, on-line device to be used during manufacture of wind-tunnel models for the U.S. National Transonic Facility at NASA Langley Research Center. The scattering geometries for the two instruments are compared and results from these instruments and the stylus technique are shown for roughness specimens typical of the surface finish of wind-tunnel models.

*National Bureau of Standards, Gaithersburg, MD 20877 U.S.A.

398. *Hall, R. M.: **Studies of Condensation Effects on Airfoil Testing in a Transonic Cryogenic Tunnel.** Presented at the AIAA 23rd Aerospace Sciences Meeting, Reno, Nev., January 14-17, 1985, 12 pp., 16 refs.

AIAA Paper 85-0229 A85-19603#

Note: For a later version of this report see citation no. [443] in this bibliography.

In the context of an overall development of transonic, cryogenic wind-tunnel technology, NASA has been studying the onset of condensation effects in nitrogen gas. The temperature at which condensation occurs determines the minimum operating temperature of cryogenic tunnels. The apparatus and airfoils are discussed, taking into account a description of the 0.3-m Transonic Cryogenic Tunnel (TCT), the drag rake, the airfoils, and the technique used for determining the onset of condensation effects. Attention is also given to the types of nucleation processes, the relative sensitivity of drag rake and surface-pressure measurements, correlations between data and theory, the prediction of minimum operating temperatures for the 0.3-m TCT, and the minimum operating temperatures for different tunnels.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

399. *Lawing, P. L.; *Dress, D. A.; and *Kilgore, R. A.: **Description of the Insulation System for the Langley 0.3-Meter Transonic Cryogenic Tunnel.** NASA TM-86274, January 1985, 25 pp., 12 refs.

N85-15755#

This paper describes the thermal insulation system of the NASA Langley 0.3-meter Transonic Cryogenic Tunnel. The insulation system is designed to operate from room temperature down to about 77.4 K, the temperature of liquid nitrogen at 1 atm. A detailed description is given of the primary insulation system which consists of glass fiber mats, a three-part vapor barrier, and a dry nitrogen positive-pressure purge system. Also described are several secondary insulation systems required for the test section, actuators, and tunnel supports. An appendix briefly describes the original insulation system considered inferior to the one now in place. The time required for opening and closing portions of the insulation system for modification or repair to the tunnel has been reduced, typically from a few days for the original thermal insulating system to a few hours for the present system.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

400. *Schmidt, W.: **European Transonic Wind Tunnel.** In: Dornier Post (English Edition) no. 1, January 1985, pp. 40-42.

ISSN 0012-5563 A85-37491#

In virtue of energy-related cost-reduction criteria, a low-temperature gas-flow concept has been chosen for the design development of the projected European Transonic Windtunnel (ETW). An attempt is presently made to ascertain whether, in wind tunnels using nitrogen cooled close to it liquefaction point, flow-simulation distortions could be generated by the influence of real-gas effects, local condensation, and heat-transfer problems. Attention is accordingly given to material property requirements and requisite degree of geometric accuracy for ETW aircraft models, as well as the ETW diffuser throat design.

*Dornier GmbH–Friedrichshafen 1, Postfach 1420, D-7990 Friedrichshafen 1, FRG

401. *Rush, H. F., Jr.; and *Firth, G. C.: **Initial Investigation of Cryogenic Wind Tunnel Model Filler Materials.** NASA TM-86363, January 1985, 23 pp., 4 refs.

N85-18069#

Various filler materials are being studied for applicability to cryogenic wind-tunnel models. The filler materials will be used to fill surface grooves, holes, and flaws. The severe test environment of cryogenic models precludes using filler materials used on conventional wind-tunnel models. Coefficients of thermal expansion, finishing characteristics, adhesion, and stability of several candidate filler materials have been examined. Promising filler materials are identified.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

402. *Cole, S. R.: **Exploratory Flutter Test in a Cryogenic Wind Tunnel.** NASA TM-86380, February 1985, 10 pp., 9 refs. Also: Journal of Aircraft, vol. 23, December 1986, pp. 904-911, 9 refs.

N85-21689#

Note: For another form of this paper see citation no. [404] in this bibliography.

An experimental study to explore the feasibility of conducting flutter tests in cryogenic wind tunnels was made in the NASA

Langley 0.3-m Transonic Cryogenic Tunnel (TCT). The model consisted of a rigid wing with an integral, flexible beam support cantilever mounted from the tunnel wall. The wing had a rectangular planform of aspect ratio 1.5 and a 64A010 airfoil. Various considerations and procedures for conducting flutter tests in a cryogenic wind tunnel were evaluated. Flutter onset conditions were established from extrapolated subcritical response measurements. A flutter boundary was determined at cryogenic temperatures over a Mach number, M, range from 0.5 to 0.9. Flutter was obtained at two different Reynolds numbers R at M = 0.5 (R = 4.4 and 18.4 million) and at M = 0.8 (R = 5.0 and 10.4 million). Flutter analyses using subsonic lifting surface (kernal function) aerodynamics were made over the range of test conditions. To evaluate the Reynolds number effects at M = 0.5 and 0.8, the experimental results were adjusted using analytical trends to account for differences in the model-test temperatures and mass ratios. The adjusted experimental results indicated increasing Reynolds number from 5.0 to 20.0 million decreased the flutter dynamic pressure by 4.0 to 6.5 percent at M = 0.5 and 0.8. The Reynolds number effects may possibly be within the scatter band of the experimental measurements.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

403. *Bazin, M.: **Test of the ONERA Cryogenic Balance in the T2 Wind Tunnel of CERT. Final Report** [Essai De La Balance Cryogenic ONERA dans la Soufflerie T2 du CERT.] ONERA-BT-8/0791-GY, February 1985, 26 pp., 11 refs., in French.

N86-13341#

Balance qualification tests in the T2 wind tunnel are described. The feasibility of force measurement in cryogenic conditions was studied. The tests confirm accurate functioning in the temperature range 100 to 300 K, showing a good compensation of electrical and mechanical temperature effects. The observed thermal gradients do not influence the required precision of one per thousand of the balance capacity.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France
Contract: DRET-83-34-135

404. *Cole, S. R.: **Exploratory Flutter Test in a Cryogenic Wind Tunnel.** Presented at the AIAA 26th Structures, Structural Dynamics, and Materials Conference held at Orlando, Fla., April 15-17, 1985. In: Technicai Papers, Part 2, (A85-30226#), 1985, pp. 426-434. Also: Journal of Aircraft, vol. 23, December 1986, pp. 904-911, 9 refs.

AIAA Paper 85-0736 A85-30369#

Note: For an earlier form of this report and an abstract see citation no. [402] in this bibliography.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

405. *Goodyer, M. J.: **Introduction to Cryogenic Wind Tunnels.** Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind-Tunnel Testing, AGARD-R-722, (N86-20415#), 1985, pp. 1-1 through 1-12, and held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, 15 refs.

N86-20416#

Note: This paper was published later as NASA CR-177966, September 1985, citation no. [434] in this bibliography.

The background to the evolution of the cryogenic wind tunnel is outlined, with particular reference to the late 60s/early 70s when efforts were begun to re-equip with large wind tunnels. The problems of providing full scale Reynolds numbers in transonic testing were proving particularly intractable, when the notion of satisfying the needs with the cryogenic tunnel was proposed and then adopted. The principles and advantages of the cryogenic tunnel are outlined, along with guidance on the coolant needs when this is liquid nitrogen, and with a note on energy recovery. Operational features of the tunnels are introduced with reference to a small low-speed tunnel. Finally the outstanding contributions are highlighted of the 0.3-meter Transonic Cryogenic Tunnel (TCT) at NASA Langley Research Center, and its personnel, to the furtherance of knowledge and confidence in the concept.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

406. *Wigley, D. A.: **Basic Cryogenics and Materials.** Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, AGARD-R-722, (N86-20415#) 1985, pp. 2-1 through 2-18, and held at the von Karman Institute, Rhode-Saint Genèse, Belgium, April 22-26, 1985, 19 refs.

N86-20417#

The effects of cryogenic temperatures on the mechanical and physical properties of materials are summarized. Heat capacity and thermal conductivity are considered in the context of conservation of liquid nitrogen, thermal stability of the gas stream, and the response time for changes in operating temperature. Particular attention is given to the effects of differential expansion and failure due to thermal fatigue. Factors affecting safety are discussed, including hazards created due to the inadvertent production of liquid oxygen and the physiological effects of exposure to liquid and gaseous nitrogen, such as cold burns and asphyxiation. The preference for using f.c.c. metals at low temperatures is explained in terms of their superior toughness and the limitations on the use of ferritic steels is also considered. Non-metallic materials are discussed, mainly in the context of their LOX compatibility and their use as foams and fibers as insulants, seals, and fiber-reinforced composites.

*Applied Cryogenics and Materials Consultants, Inc., 15 Cantamar Court, Hampton, VA 23664 U.S.A. or
Cryogenic, Marine and Materials Consultants Ltd., 17 Bassett Wood Drive, Bassett, Southampton SO2 3PT, England

407. *Wigley, D. A.: **Materials and Techniques for Model Construction.** Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, AGARD-R-722, (N86-20415#) 1985, pp. 3-1 through 3-19, 31 refs., and held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985.

N86-20418#

The problems confronting the designer of cryogenic wind-tunnel models are discussed with particular reference to the difficulties in obtaining appropriate data on the mechanical and physical properties of candidate materials and their fabrication technologies. The relationship between strength and toughness of alloys is discussed in the context of maximizing both and avoiding the problem of dimensional and microstructural instability. All major classes of materials used in model construction are considered in some detail. In the Appendix, selected numerical data is given for the most relevant materials. The stepped-specimen program to investigate stress-induced dimensional changes in alloys is discussed in detail together with interpretation of the initial results. The methods used to bond-model components are considered with particular reference to the selection of filler alloys and temperature cycles to avoid microstructural degradation and loss of mechanical properties.

*Applied Cryogenics and Materials Consultants, Inc., 15 Cantamar Court, Hampton, VA 23664 U.S.A. or
Cryogenic, Marine and Materials Consultants Ltd., 17 Bassett Wood Drive, Bassett, Southampton SO2 3PT, England

408. *Young, C. P., Jr.: **Design and Construction of Models for the National Transonic Facility - I.** Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, AGARD-R-722, (N86-20415#) 1985, pp. 4-1 through 4-17, 24 refs.

N86-20419#

The design and construction of models for the U.S. National Transonic Facility (NTF) have resulted in significant technology development in many areas. This lecture covers the development or design criteria and major research and development work that has contributed to the successful design and fabrication of models for testing at full-scale Reynolds number in the NTF. Emphasis is placed on the materials aspect of the design and fabrication process including metallic materials, mechanical properties characterization, new steel alloy development, fracture-toughness enhancement, and identification of fillers and solders suitable for use in cryogenic models. Quantitative data are provided which will be of value to the potential user of NTF or for application to the design and fabrication of model systems for other cryogenic wind tunnels.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

409. *Young, C. P., Jr.: **Design and Construction of Models for the National Transonic Facility - II.** Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, AGARD-R-722, (N86-20415#) 1985, pp. 5-1 through 5-16, and held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, 10 refs.

N86-20420#

This lecture presents the results of fastener load and retention systems tests carried out as a part of the cryogenic models technology development program at the NASA Langley Research Center. Various design concepts for the U.S. National Transonic Facility (NTF) developmental and production models are discussed. A number of NTF models are described with emphasis on materials used, uniqueness of design, and design drivers. Design and fabrication experience is presented in terms of the primary thermal and mechanical considerations required for design as well as fabrication. Cost considerations are addressed in terms of factors influencing costs for NTF models and cost data comparisons which are taken from both NASA Langley and industry experience.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

410. *Bazin, M.: **Cryogenic Wind Tunnel Instrumentation.** Presented at the AGARD-FDP-VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, AGARD-R-722, (N86-20415#) 1985, pp. 6-1 through 6-29, and held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, 20 refs.

N86-20421#

Research conducted under the European Transonic Wind Tunnel (ETW) project with the objective of adapting wind-tunnel instrumentation to cryogenic conditions is reviewed. In particular, attention is given to the development of cryogenic balances, pressure transducers, accelerometers, temperature transducers, skin-friction gages, and instruments for attitude and deformation measurements. Model instrumentation and model motorization are also discussed.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

411. *Mignosi, A.: **Fundamental Reflections on Cryogenic Testing.** Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, AGARD-R-722, (N86-20415#) 1985, pp. 7-1 through 7-25, and held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, 35 refs.

N86-20422#

This paper concerns a number of aerodynamic problems related to cryogenic testing but which can also be encountered during testing at room temperature. The first part describes the various factors needed to achieve the best similarity possible between an aircraft in flight and the model in the wind tunnel. The second part covers the analysis of these factors: effects of a nonadiabatic wall, boundary-layer transition, two-dimensional testing, and effects of the Reynolds number. In the paper, an attempt is made to alternate theoretical considerations with practical examples to illustrate the importance of experimental/theoretical correlations. Finally, the paper endeavors to highlight a few areas to which effort must be devoted in the future so the new technique of cryogenic wind tunnels now available to scientists and manufacturers provides reliable and accurate results leading to a better analysis of aerodynamic phenomena and improved prediction and optimization of aircraft performance.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

412. *Christophe, J.: **Productivity: The Economic Aspects of Cryogenic Wind Tunnel Design and Use.** Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, AGARD-R-722, (N86-20415#) 1985, pp. 8-1 through 8-11, and held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, 36 refs.

N86-20423#

The idea of productivity, as it is applied to large non-cryogenic wind tunnels is examined. These considerations can be extended to the new cryogenic wind tunnels; but these have some special features we attempt to define precisely. Important focal points in designing a cryogenic wind tunnel for good productivity in operation are examined.

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413. *Dor, J.-B.: **The T2 Cryogenic Induction Tunnel in Toulouse.** Presented at the AGARD FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, AGARD-R-722, (N86-20415#) 1985, pp. 9-1 through 9-24, and held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, 15 refs.

N86-20424#

This paper summarizes the main results obtained by the experimental activity at the ONERA/CERT T2 induction tunnel in Toulouse since it was converted for cryogenic operation in 1981. T2 is an induction-driven transonic tunnel fitted with a test section equipped with two self-adapting walls. This paper describes the main characteristics of this facility and its adaptation to cold flows; including the internal thermal insulation, cooling by injection of liquid nitrogen, and a system for precooling airfoil models and introducing them in the test section. The following subjects concerning cryogenic operation are then discussed: pressure and temperature fluctuations, thermal behavior of the walls, transverse temperature distributions in the flow, thermal equilibrium of an airfoil with the fluid, condensation phenomena in the cold flow, and problems of particles. Finally, the test results at high Reynolds number on a CAST 7 profile with a 150 mm chord are given.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

414. *Hefer, G.: **The Cryogenic Ludwieg Tube Tunnel at Göttingen**. Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, AGARD-R-722 (N86-20415#) 1985, pp. 10-1 through 10-6, and held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, 3 refs.

N86-20425#

A cryogenic-Ludwieg-tube wind tunnel for transonic operation is under construction at the DFVLR Research Center in Göttingen. The tunnel will have an effective run time of 1 second, a test section of 0.4 × 0.35 m, and a stagnation pressure of 10 bars. It is to be operated with nitrogen at temperatures between ambient and 120 K, achieving a Reynolds number of 70 million based on a model chord of 0.15 m. In addition to reviewing the Ludwieg tube concept, this paper presents the main features of design and operation of the tunnel.

*DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

415. *Viehweger, G.: **The Kryo-Kanal-Köln Project, KKK.** Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, AGARD-R-722, (N86-20415#) 1985, pp. 11-1 through 11-20, and held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, 21 refs.

N86-20426#

The Kryo-Kanal-Köln (KKK) project aims at the modification of a low-speed wind tunnel to cryogenic operation. The basis for this decision of the DFVLR consisted in establishing a possibility at a reasonable price for gathering the know-how for the later use of the European Transonic Windtunnel (ETW). The construction is essentially completed and has required about five years. The facility, with a test section of 2.4 × 2.4 m, has been designed to operate in a temperature range from 100 to 300 K. The checkout of all systems will start in April 1985.

*DFVLR–Porz-Wahn, Postfach 90 60 58, D-5000 Köln 90 Porz-Wahn, FRG

416. *Tizard, J. A.; and *Hartzuiker, J. P.: **The European Transonic Windtunnel Project ETW.** Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, AGARD-R-722, (N86-20415#) 1985, pp. 12-1 through 12-23, and held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, 9 refs.

N86-20427#

A general description of the European Transonic Windtunnel, ETW, is presented with particular reference to the tunnel specification and predicted performance; the design features related to operation at cryogenic temperatures; including the insulation concept, model access, and handling; a summary of a study on the expected use of the facility; the flow-quality requirements for ETW, including experimental results from an aerodynamic test rig; and the requirement for a second throat and its conceptual design, a brief description of the pilot ETW (PETW) which is installed at NLR, Amsterdam. Finally, a status report of the project and its anticipated future development is given.

*Technical Group ETW, c/o National Aerospace Laboratory, 1006 BM Amsterdam The Netherlands

417. *Kilgore, R. A.: **The NASA Langley 0.3-m Transonic Cryogenic Tunnel**. Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, AGARD-R-722, (N86-20415#) 1985, pp. 13-1 through 13-15, and held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, 32 refs.

N86-20428#

The NASA Langley 0.3-m Transonic Cryogenic Tunnel (0.3-m TCT) can operate from ambient to cryogenic temperatures at absolute pressures from 1 to 6 bars. Since the 0.3-m TCT began operation in 1973, it has been used to develop instrumentation and operating techniques for cryogenic tunnels as well as for aerodynamic tests where advantage can be taken of the extremely wide range of Reynolds number available. This paper describes the present capabilities of the 0.3-m TCT and gives an overview of recent research activities which include both steady and unsteady testing. Emphasis is given to safety and the development of testing techniques for cryogenic tunnels. Results of studies aimed at establishing the lower limits of operating temperature are presented and the impact of these studies on tunnel operation is discussed. Finally, the design features and operating characteristics of a new self-streamlining-wall test section recently installed in the tunnel circuit are described.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

418. *Bruce, W. E., Jr.: **The U.S. National Transonic Facility - I.** Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, AGARD-R-722, (N86-20415#) 1985, pp. 14-1 through 14-10, and held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, 12 refs.

N86-20429#

The construction of the U.S. National Transonic Facility (NTF) was completed in September 1982, and checkout operations started the following month, with the maximum design Reynolds number being obtained in May 1983. Following initial operation, most of the effort was devoted to installing the model access housing and adjusting or altering various tunnel hardware systems. In

May 1984, preliminary checkout of the tunnel started in parallel with checkout of the tunnel operating systems. The tunnel has been operated in both the air and nitrogen modes covering a Mach number range of 0.2 to 1.22, at pressures up to 8.5 atm, and at temperatures down to 100 K. This paper presents the status of the tunnel operating system and an overview of the major milestones during checkout.

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419. *Bruce, W. E., Jr.: **The U.S. National Transonic Facility - II.** Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing. In: AGARD-R-722, (N86-20415#) 1985, pp. 15-1 through 15-10, held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, 15 refs.

N86-20430#

The construction of the U.S. National Transonic Facility (NTF) was completed in September 1982 and checkout operations started the following month with the maximum Reynolds number being obtained in May 1983. Afterwards, effort was primarily devoted to installing the model access housings and adjusting or altering various tunnel hardware systems. In May 1984, the aerodynamic calibration started in parallel with checkout of the tunnel systems. In August 1984, the final-operational-readiness review was conducted and the tunnel declared operational for research testing. The tunnel has been operated in both air and nitrogen modes covering a Mach number range of 0.2 to 1.22 at pressures up to 8.5 atm and at temperatures down to 100 K. A limited amount of tunnel-circuit-performance information has been obtained and is presented in this paper. An aerodynamic calibration plan has been outlined and the first part of the steady-state calibration has been completed, of which some results are presented in this paper. The first aerodynamic vehicle, Pathfinder I, was installed in December 1984 for checkout of instrumentation systems and a status report and some results are presented.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

420. *Kilgore, R. A.: **Other Cryogenic Wind-Tunnel Projects.** Presented at the AGARD-FDP/VKI Special Course on Cryogenic Technology for Wind Tunnel Testing, AGARD-R-722, (N86-20415#) 1985, pp. 16-1 through 16-15, and held at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985, 33 refs.

N86-20431#

Following the development of the cryogenic wind tunnel at the NASA Langley Research Center in 1972, many cryogenic wind-tunnel projects have been undertaken at various research establishments around the world. Described in this lecture are cryogenic wind-tunnel projects in China (Chinese Aeronautical Research and Development Center), England (College of Aeronautics at Cranfield, Royal Aircraft Establishment - Bedford, and University of Southampton), Japan (National Aerospace Laboratory, University of Tsukuba, and National Defense Academy), Sweden (Rollab), and the United States (Douglas Aircraft Co., University of Illinois at Urbana-Champaign, and NASA Langley).

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

421. *McKinney, L. W.; and *Fuller, D. E.: **Preliminary Calibration and Test Results From the National Transonic Facility.** Presented at the NASA Langley Symposium on Aerodynamics held at NASA Langley Research Center, Hampton, Va., April 23-25, 1985. In: Vol. I, (N88-14926) pp. 311-332.

N88-14941#

The U.S. National Transonic Facility (NTF) was operated to design condition of 120 million Reynolds number at a Mach number of 1.0. All systems were checked out except plenum isolation valves; modifications are being made to heaters on the actuators. Initial steady-state calibration indicates excellent steady-flow characteristics. The first test of the Pathfinder I model showed significant Reynolds number effects. Some effects of temperature on instrumentation were obtained. The cause of these effects is being evaluated.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

422. *Honaker, W. C.; and *Lawing, P. L.: **Measurements in the Flow Field of a Cylinder with a Laser Transit Anemometer and a Drag Rake in the Langley 0.3-m Transonic Cryogenic Tunnel**, NASA TM-86399, April 1985, 25 pp., 9 refs.

N85-24270#

An experiment in the 0.3-m Transonic Cryogenic Tunnel (TCT) used a Laser Transit Anemometer (LTA) to probe the flow field around a 3.05 centimeter diameter circular cylinder. Measurements were made along the stagnation line and determination of particular size was evaluated by their ability to follow the flow field. The LTA system was also used to scan into the boundary layer near the 45 degree point on the model. Results of these scans are presented in graphic and tabular form. Flow-field particle seeding was accomplished by inbleeding dry-service air. The residual moisture (5-10 ppm) condensed and formed ice particles which served as Mie scattering centers for the LTA detection system. Comparison of data taken along the stagnation streamline with theory indicated that these particles tracked the velocity gradient of the flow. Tunnel operating conditions for the tests were a Mach number of 0.3, a pressure of 1.93×10^5 n/m^2, and a temperature of 225 K. Free-stream Mach number and pressure were varied for the particle size determination.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

423. *Steinhauser, R.: **Control System Design for Cryogenic Wind Tunnel by Performance Vector Performance.** Ph.D. Thesis - Karlsruhe Univ., Germany. DFVLR-FB-85-37, April 1985, 191 pp., 116 refs., in German.

N86-15329#

Note: For an English translation and an abstract of this thesis see citation no. [445] in this bibliography.

*DFVLR–Wessling/Obb., Oberpfaffenhofen, D-8031 Wessling/Obb., FRG

424. *North, R. J.; *Schimanski, D.; and *Hartzuiker, J. P., editors: **Cryogenic Test Technology, 1984.** AGARD-AR-212, April 1985, 28 pp., 47 refs.

ISBN 92-835-1496-3 N85-29116#

This report reviews the new information available on cryogenic test technology since the report of the Conveners' Group on Cryogenic Test Technology was written in 1981. The present position is summarized. The major events since the Conveners' report have been the completion and commissioning of the U.S. National Transonic Facility (NTF), the suspension of further work on the Douglas 4-CWT blowdown tunnel, the conversion of the ONERA T2 for cryogenic operation, the steady progress with the DFVLR KKK, and the slow but positive progress with the ETW project, including installation of the pilot tunnel PETW.

*Technical Group ETW, c/o National Aerospace Laboratory, 1006 BM Amsterdam, The Netherlands

425. *Burner, A. W.; *Snow, W. L.; and *Goad, W. K.: **Model Deformation Measurements at a Cryogenic Wind Tunnel Using Photogrammetry.** Presented at the 31st International Instrumentation Symposium, San Diego, Calif.; May 6-9, 1985. In: Proceedings (A86-38051) pp. 615-622, 12 refs.

A86-38073

A photogrammetric-closed-circuit television system to measure model deformation at the U.S. National Transonic Facility (NTF) is described. The photogrammetric approach was chosen because of its inherent rapid data recording of the entire object field. Video cameras are used to acquire data instead of film cameras due to the inaccessibility of cameras which must be housed within the cryogenic, high-pressure plenum of the tunnel. Data reduction procedures and the results of tunnel tests at the NTF are presented.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

426. *Kern, F. A.; *Knight, C. W.; and *Zasimowich, R. F.: **National Transonic Facility Mach Number System.** Presented at the 31st International Instrumentation Symposium, San Diego, Calif., May 6-9, 1985. In: Proceedings (A86-38051). Research Triangle Park, NC, Instrumentation Society of America, 1985, pp. 643-652, 3 refs.

A86-38076

The Mach number system for the U.S. National Transonic Facility (NTF) was designed to measure pressures to determine Mach number to within ±0.002. Nine calibration laboratory-type fused quartz gages, four different range gages for the total-pressure measurement, and five different range gages for the static pressure measurement were used to satisfy the accuracy requirement over the 103,000-890,000 Pa total-pressure range of the tunnel. The system, which has been in operation for over 1 year, is controlled by a programmable data process controller to select, through the operation of solenoid valves, the proper range-fused quartz gage to maximize the measurement accuracy. The analog outputs of the pressure gages are digitized by the process controller and transmitted to the main computer for Mach number computation. An automatic two-point on-line calibration of the nine quartz gages is provided using a high-accuracy mercury manometer.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

427. *Alekseyev, L. P.; and *Fuks, M. A.: **A Cryogenic Wind Tunnel.** Rep. FTD-ID(RS)T-0151085. Translation into English (May 7, 1985) from Trudy Giproniiaviaprom (USSR), no. 19, 1983, pp. 13-22. Air Force Systems Command, Wright-Patterson AFB, Ohio. (Foreign Technology Division.)

AD-B092296L X85-76639#
AD-E401344

Note: For the original Russian form, see citation no. [364] in this bibliography.

*U.S.S.R.

428. *Advisory Group for Aerospace Research and Development (AGARD): **Cryogenic Technology for Wind Tunnel Testing,** AGARD-R-722, July 1985, 408 pp., an AGARD Special Course directed by R. A. Kilgore under the sponsorship of the Fluid Dynamics Panel of AGARD and implemented by and presented at the von Karman Institute, Rhode Saint Genèse, Belgium, April 22-26, 1985.

ISBN-92-835-1506-4 N86-20415#

Note: Papers presented are placed under the date of presentation, see citation nos. [405 through 420] in this bibliography.

Following a brief review of the development and early use of cryogenic wind tunnels, the 16 lectures examine the following aspects of cryogenic wind-tunnel technology related to the design and operation of cryogenic tunnels: cryogenic engineering and safety, properties of materials at cryogenic temperatures, model-design requirements of materials at cryogenic temperatures, model-design requirements and fabrication techniques, instrumentation for control and data acquisition, data accuracy, productivity, and costs of models and operation. A review of the status of cryogenic wind-tunnel projects is also presented.

*AGARD (Advisory Group for Aerospace R&D), NATO, 7 rue Ancelle, 92200 Neuilly sur Seine, France

429. *Blanchard, A.; *Seraudie, A.; *Plazanet, M.; and *Payry, M. J.: **Essai de la Balance Probatoire Cryogenique ONERA dans la Soufflerie T2.** Rept. no. DERAT-TR-22/5007-DN), July 1985, 47 pp., 6 refs., in French.

N87-24485#

Note: For an English translation of this report see citation no. [496] in this bibliography.

A three-component cryogenic balance designed and built by ONERA, was fitted with a light alloy model and tested at the end of 1984 in the T2 wind tunnel in flows at temperatures down to 120 K. The tests were to determine the effect of cryogenic operation on the behavior of balance while cooling the balance-model system mounted in the conditioning device and during tests with models in the test section. A few tests with thermal disequilibrium between the flow and balance made it possible to confirm proper operation in the range 120 - 300 K. These tests showed that the balance, which was well compensated thermally, may be used in T2 with or without precooling. For any thermal gradient, the analysis was always made with the same matrices and the aerodynamic coefficients were obtained with the same precision.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

430. *Holmes, H. K.: **Model Measurements in the Cryogenic National Transonic Facility–An Overview.** Presented at the 11th International Congress on Instrumentation in Aerospace Simulation

Facilities, Stanford, Calif., August 26-28, 1985. In: ICIASF '85 RECORD, IEEE publication 85CH2210-3, pp. 1-8.

TK7882.M415, 1985, pp. 1-8 A86-38227#

Note: For another form of this paper see citation no. [446] in this bibliography.

In the operation of the U.S. National Transonic Facility (NTF) high Reynolds numbers are obtained by using low operational temperatures and high pressures. Liquid nitrogen is used to cool the tunnel to cryogenic temperatures. Temperatures in the range from -320 to 160 °F can be used. A maximum pressure of 130 psi is specified, while the NTF design Reynolds number is 120 million. In view of the new requirements of the measurement systems, major developments had to be undertaken in virtually all wind-tunnel measurement areas. In addition, some new measurement systems were needed. Attention is given to force measurement, pressure measurement, model attitude, model deformation, and the data system.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

431. *Archambaud, J.-P.; *Blanchard, A.; and *Seraudie, A.: **Instrumentation and Testing Techniques in the T2 Transonic Cryogenic Wind Tunnel at the ONERA-CERT.** Presented at the 11th International Congress on Instrumentation in Aerospace Simulation Facilities, Stanford, Calif., August 26-28, 1985. In: ICIASF '85 RECORD, IEEE publ. 85CH2210-3, pp. 9-25, 16 refs.

TK7882.M415, 1985, pp. 9-25 A86-38228

The T2 induction wind tunnel is equipped to reach high Reynolds numbers, up to 30 million. The following three parameters are directly concerned with these high Reynolds numbers: pressure, model size, and temperature. The T2 closed circuit can be pressurized up to 4 atm. Large models (c = 200 mm) were tested in the 0.4 × 0.4 m test section fitted with two-dimensional self-adaptive walls. The adaptation of the top and bottom solid walls is achieved by an iterative process which converges during a run. The air flow is cooled down to 110 K and consequently new model designs and manufacture proceedings are required. Before the run, the model must be precooled in an auxiliary facility. The measurement techniques were necessarily adapted to low-temperature conditions. Measurements were made with skin-friction gauges, cryogenic pressure transducer probes, and a three-component balance.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

432. *Gobert, J. L.: **Data Acquisition and Process Control in the Self-Correcting Cryogenic Wind Tunnel T2 at ONERA/CERT by Integration of Two Minicomputers.** Presented at the 11th International Congress on Instrumentation in Aerospace Simulation Facilities, Stanford, Calif., August 26-28, 1985. In: ICIASF '85 RECORD, IEEE publ. 85CH2210-3, pp. 26-35, 7 refs.

TK7882.M415, 1985, pp. 26-35 A86-38229

The transonic induction T2 wind tunnel at CERT in Toulouse is equipped with adaptive walls and has been operating at cryogenic temperature since 1981. Problems were caused by the intermittent working of the tunnel. New operating techniques were developed such as control of the flow parameters and data acquisition while the walls were being used adaptively. Two linked computers satisfactorily defined conditions in the T2 wind tunnel during the testing of an airfoil.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

433. *Macha, J. M.; *Pare, L. A.; and *Landrum, D. B.: **A Theoretical Study of Non-Adiabatic Surface Effects for a Model in the NTF Cryogenic Wind Tunnel,** October 1, 1983 - January 31, 1985. NASA CR-3924, August 1985, 58 pp., 18 refs.

N85-34352

A theoretical analysis has been made of the severity and effect of nonadiabatic surface conditions for a model in the U.S. National Transonic Facility (NTF). The non-adiabatic condition arises from heaters that are used to maintain a constant thermal environment for instrumentation inside to the model. The analysis was made for several axisymmetric representations of a fuselage cavity, using a finite-element heat conduction code. Potential flow and boundary-layer codes were used to calculate the convection boundary condition for the exterior surface of the model. The results of the steady-state analysis show it is possible to maintain the surface temperature very near the adiabatic value, with the judicious use of insulating material. Even for the most severe non-adiabatic condition studied, the effects on skin-friction drag and displacement thickness were only marginally significant. The thermal analysis also provided an estimate of the power required to maintain a specified cavity temperature.

*Texas A&M Research Foundation, College Station, TX 77843 U.S.A.
Contract: NAG1-417

434. *Goodyer, M. J.: **Introduction to Cryogenic Wind Tunnels.** NASA CR-177966, September 1985, 13 pp., 15 refs.

N86-12238#

Note: For an earlier form and an abstract of this report see citation no. [405] in this bibliography, AGARD-R-722, Paper I.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton, Hampshire SO9 5NH, England
Contract: NAS1-17919

435. *Lawing, P. L.: **The Construction of Airfoil Pressure Models by the Bonded Plate Method: Achievements, Current Research, Technology Development and Potential Applications.** NASA TM-87613, September 1985, 34 pp., 18 refs.

N86-16234#

This paper describes a method of building airfoils by inscribing pressure channels on the face of opposing plates, bonding them together to form one plate with integral channels, and machining this plate to the desired contour. The research and development program to develop the bonding technology is described as well as the construction and testing of an airfoil model. Sample aerodynamic data sets are presented and discussed. Also, work under way to produce thin airfoils with camber is presented. Samples of the aft section of a 6 percent airfoil with complete pressure instrumentation, including the trailing edge, are pictured and described. This technique is particularly useful in building models for transonic cryogenic testing, but it should find use in a wide range of model construction projects, as well as the fabrication of fuel injectors, space hardware, and other uses requiring advanced bonding technology and intricate fluid passages.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

436. *Adachi, T.; *Matsuuchi, K.; **Matsuda, S.; and *Kawai, T.: **On the Force and Vortex Shedding on a Circular Cylinder from Subcritical up to Transcritical Reynolds Numbers.** Bulletin of the JSME (In English), vol. 28, no. 243, September 1985, pp. 1906-1909, 10 refs.

ISSN 0021-3764 A86-16840#

Note: Previously published in the Transactions of the Japanese Society of Mechanical Engineers, January 1985, in Japanese.

Static pressure distributions were measured in the test section of a newly built cryogenic tunnel using a cylindrical model with a diameter of 50 mm and a relative surface roughness of 10^{-5}. The drag acting on the cylinder was calculated and vortex shedding frequencies were determined for Reynolds numbers between 100,000 and 10 million. Typical results were obtained for the surface static pressure distributions in the subcritical, lower transition, critical, upper transition, and transcritical Reynolds number ranges. The calculated drag coefficient also shows typical characteristics for each Reynolds number range. The Strouhal number is constant in the subcritical and lower transition ranges, but not constant in the supercritical range. For Reynolds numbers of 570,000 and higher, it is constant again.

*University of Tsukuba, Sakura, Japan
**Mitsubishi Heavy Industries Co., Tokyo, Japan

437. *Amecke, J.: **Energy-Saving Cycle for Continuous Cryogenic Wind Tunnels (Energiesparender Kreislauf für kontinuierliche Kryo-Windkanäle).** Presented at DGLR, Jahrestagung, (German Aerospace Society Annual Convention), Bonn, Germany, September 30 - October 2, 1985, 23 pp., 6 refs., in German. English translation is NASA TM-88412, (X86-10258), April 1986.

DGLR Paper 85-093 A86-35156

In connection with the achievement of high Reynolds numbers, the operation of wind tunnels at very low temperatures has great advantages. The cooling process provided involves generally the injection of liquid nitrogen. However, the implementation of this approach is costly. The present study is, therefore, concerned with the possibility of replacing the current procedure by a more cost-efficient process. An analysis is made of the minimum power needed to operate a wind tunnel, and an estimate is obtained of the power consumed in conventional cryogenic wind tunnels. It is found that current cryogenic wind tunnels consume considerably more power than is actually needed. A study is made of the possibilities available to design a procedure which comes closer to the characteristics of the ideal process. The basic element of the obtained improved cycle is a counterflow heat exchanger.

*DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

438. *Kilgore, R. A.; *Dress, D. A.: **A Survey of Cryogenic Wind Tunnels.** Presented at the Technische Universitä Berlin, Institut für Luft-und Raumfahrt, Berlin, Germany, October 18, 1985, 33 pp., 43 refs.

A86-17853#

Following the development of the cryogenic wind tunnel at the NASA Langley Research Center in 1972, a large number of cryogenic wind-tunnel projects have been undertaken at various research establishments around the world. The purpose of this paper is to describe some of the more significant of these projects. Described in this paper are cryogenic wind-tunnel projects in China (CARDC), England (College of Aeronautics at Cranfield, RAE-Bedford, and University of Southampton), 'Europe' (Pilot European Transonic Windtunnel at NAL-Amsterdam, and the European Transonic Windtunnel proposed for DFVLR-Köln), France (ONERA-CERT), Germany (DFVLR-Köln, and DFVLR- Göttingen), Japan (NAL, University of Tskuba, and National Defense Academy), Sweden (Rollab), and the United States (Douglas Aircraft Co., University of Illinois at Urbana-Champaign, and NASA Langley).

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

439. *Pan, R.: **Cryogenic High Reynolds Number Transonic Wind Tunnel with Pre-cooled and Restricted Flow.** In: ACTA Aerodynamica Sinica (selected articles) (FDT-ID(RS)T-0493-85), November 22, 1985, 95 pp., Translated into English from Zhongguo Quiliu Dongli Xue (China), no. 2, pp. 76-92, 7 refs.

AD-A162351, pp. 76-92 N86-23574#, pp. 76-91

Note: For the original Chinese form of this document see citation no. [383] in this bibliography.

In order to achieve the full-scale Reynolds number of aircraft in model testing, various high-Reynolds-number transonic wind tunnels are being developed abroad. In this paper, a cryogenic high-Reynolds-number transonic wind tunnel with pre-cooled and restricted flows is presented. The principle that air temperature falls down through a flow restrictor, which is also a regulator, is applied. Air from a compressor is first cooled to 215 K and then enters into the pressure vessels. During the wind-tunnel operation the regulating valve must be controlled, so that fluid pressure is 5 atm and its temperature is 154 K. Under the different Mach number condition, the different temperature and pressure may be used to achieve a Reynolds number as high as 16.7×10^7. In this paper, the cooling system of the wind tunnel and the tunnel operating principles are described in detail, as well as the 2.4 m transonic wind-tunnel scheme.

*China Aerodynamic Research and Development Center (CARDC), P. O. Box 211, Mianyang, Sichuan, China

440. *Dress, D. A.: **Computer Program for Calculating Flow Parameters and Power Requirements for Cryogenic Wind Tunnels.** NASA TM-87609, November 1985, 41 pp., 17 refs.

N86-13338#

A computer program has been written that performs the flow parameter calculations for cryogenic wind tunnels which use nitrogen as a test gas. The flow parameters calculated include static pressure, static temperature, compressibility factor, ratio of specific heats, dynamic viscosity, total and static density, velocity, dynamic pressure, mass-flow rate, and Reynolds number. Simplifying assumptions have been made so the calculations of Reynolds number, as well as the other flow parameters, can be made on relatively small desktop digital computers. The program, which also includes various power calculations, has been developed to the point where it has become a very useful tool for the users and designers of fan-driven continuous-flow cryogenic wind tunnels.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

441. *Zalenski, M. A.; *Rowe, E. L.; *McPhee, J. R.: **Operational Considerations in Monitoring Oxygen Levels at the National Transonic Facility.** NASA CR-3953, December 1985, 19 pp.

N86-17359#

Laboratory monitoring of the level of oxygen in sample gas mixtures is a process which can be performed with accurate and repeatable results. Operations at the U.S. National Transonic Facility require the storage and pumping of large volumes of liquid nitrogen. To protect against the possibility of a fault resulting in a localized oxygen-deficient atmosphere, the facility is equipped with a monitoring system with an array of sensors. During the early operational states, the system produced recurrent alarms, none of which could be traced to a true oxygen deficiency. A thorough analysis of the system was made with primary emphasis placed on the sensor units. These units sense the partial pressure of oxygen which, after signal conditioning, is presented as a percentage by volume indication at the system output. It was determined that many of the problems experienced were due to a lack of proper accounting for the partial pressure percentage by volume relationship, with a secondary cause being premature sensor failure. Procedures were established to consider atmospherically-induced partial pressure variations. Sensor rebuilding techniques were examined, and those elements contributing to premature sensor failure were identified. The system now operates with a high degree of reliability.

*Wyle Laboratories, Inc., 3200 Magruder Blvd., Hampton, VA 23665-5225 U.S.A.
Contract: NAS1-16331

442. *Vorburger, T. V.; *McLay, M. J.; *Scire, F. E.; *Gilsinn, D. E.; and *Giauque, C. H. W.: **Surface Roughness Studies for Wind Tunnel Models Used in High Reynolds Number Testing.** Journal of Aircraft, vol. 23, January 1986, pp. 56-61, 31 refs.

ISSN 0021-8669 A86-20161#

Note: For an earlier presentation of this paper and an abstract see citation no. [397] in this bibliography.

*National Bureau of Standards, Gaithersburg, MD 20877 U.S.A.
NBS-NAVY-supported research
NASA Order L-4718-B

443. *Hall, R. M.: **Studies of Condensation Effects on Airfoil Testing in the Langley 0.3-Meter Transonic Cryogenic Tunnel.** NASA TP-2509, January 1986, 34 pp., 26 refs.

N86-20720#

Note: For an earlier form of this report see citation no. [398] in this bibliography.

The results of condensation studies in the NASA Langley 0.3-meter Transonic Cryogenic Tunnel (0.3-m TCT) using the NACA 0012-64, NPL 9510, NACA 0012, NASA SC(3)-0712(B), and CAST 10-2/DOA 2 airfoils are summarized as follows: (1) both homogeneous nucleation and condensation on pre-existing seed particles can occur depending on the value of maximum local Mach number over the airfoil; (2) if poor atomization of the liquid nitrogen (LN_2) injected to cool the tunnel occurs, it is possible for unevaporated LN_2 droplets to cause changes in a pressure distribution at total temperatures greater than those corresponding to local saturation; (3) drag measurements do not appear to be as sensitive to the onset of condensation effects as the individual pressure orifices around the airfoils; (4) a theoretical analysis by Sivier correlates well with the present airfoil data; and (5) a simple procedure is presented to predict minimum operating temperatures in the 0.3-m TCT.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

444. *Sawada, H.: **Automatic Operation of the NAL Cryogenic Wind Tunnel.** NAL News, no. 321, January 1986, pp. 2-4, in Japanese.

ISSN 0023-2726

This paper describes the 0.1 × 0.1 m Transonic Cryogenic Wind Tunnel at the National Aerospace Laboratory (NAL). In a previous paper, [no. 371 in this bibliography], the operation of this tunnel using the original manual control systems is described. In 1985 we installed automatic controls for liquid nitrogen injection, gaseous nitrogen exhaust, and fan speed. Under manual control, changing from one test condition to another took from 5 to 10 minutes. The same changes in test conditions now take only about 1 minute under fully automatic control. The automatic controls are implemented using a *NEC* microcomputer.

*National Aerospace Laboratory, 7-44-1 Jindaiji-machi Chofu-shi, Tokyo 182, Japan

445. *Steinhauser, R.: **Design of a Control System for a Cryogenic Wind Tunnel Optimizing a Vector Performance Index.** Translation into English of "Reglerentwurf für einen Tieftemperatur-Windkanal mittels Guetevektoroptimierung," DFVLR-FB-85-37; ETN-86-98247; Translation is ESA-TT-965, February 1986, 208 pp., 116 refs.

N87-11804#

Note: For the original German form of this document see citation no. [423] in this bibliography.

A cryogenic wind tunnel was transformed to reach higher Reynolds numbers using a controller design. The problem of a controller design for a nonlinear multivariable dead-time system was solved by linearization, model decomposition, discretization, and order reduction to obtain an efficient design algorithm based on pole assignment and performance vector optimization. The controller design behavior on a nonlinear model before and after performance vector optimization was studied. The optimized controller can be applied in a real wind tunnel. The reduced static pressure deviation due to performance vector optimization leads to reduced control costs for exhaust and injection of gaseous nitrogen. Further development of the control system design equipment as well as the development of a graphic interactive algorithm for the design procedure is recommended.

*DFVLR-Wessling/Obb., Oberpfaffenhofen, D-8031 Wessling/Obb., FRG

446. *Holmes, H. K.: **Model Measurements in the Cryogenic National Transonic Facility - An Overview.** In: IEEE Aerospace and Electronic Systems Magazine, vol. 1, February 1986, pp. 1-7.

ISSN 0885-8985 A86-31847#

Note: For an earlier form of this article see citation no. [76] in this bibliography.

The U.S. National Transonic Facility (NTF) is a high-Reynolds-Number wind tunnel where the increase in Reynolds Number is obtained by operating at high pressures and low temperatures. Liquid nitrogen is allowed to vaporize, making gaseous nitrogen the test gas with temperatures extending down to approximately 100 K. These factors have created unique new challenges to those developing sensors and instrumentation. Pressure vessels, thermal enclosures, or elaborate temperature compensation schemes are needed for environmental protection. Special materials are needed for sensors and model fabrication. The need was also created for a new measurement method to determine model deformation. An extensive program to develop the unique sensors and instrumentation was initiated. This paper describes the data acquisition system and systems to measure aerodynamic forces and pressures, model attitude, and model deformation.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

447. *Hartzuiker, J. P.: **The European Transonic Windtunnel ETW - Design Concepts and Plans**. Presented at the AIAA 14th Aerodynamic Testing Conference, West Palm Beach, Fla., March 5-7, 1986. In: Technical Papers (A86-24726), 1986, pp. 12-20, 3 refs.

AIAA Paper 86-0731 A86-24728#

The European Transonic Windtunnel ETW will be a cryogenic transonic wind tunnel for testing at high Reynolds numbers. The specification and performance of the wind tunnel are discussed. A number of requirements for the facility have had an impact on its design. These include the expected use of the tunnel (the operating scenario) as well as productivity. Also flow quality and control requirements have led to design concepts which are peculiar to ETW. The concepts described include insulation by means of a cold box, the nozzle and test section, a second throat as well as model access, model handling, and model temperature conditioning. The plans for realization of the wind tunnel are outlined.

*National Aerospace Laboratory, 1006 BM Amsterdam, The Netherlands

448. *Lawing, P. L.; and *Johnson, C. B.: **Summary of Test Techniques Used in the NASA Langley 0.3-meter Transonic Cryogenic Tunnel**. Presented at the AIAA 14th Aerodynamic Testing Conference, West Palm Beach, Fla., March 5-7, 1986. In: Technical Papers (A86-24726), 1986, pp. 78-88, 26 refs.

AIAA Paper 86-0745 A86-24734#

This paper describes test techniques used to obtain data in the 0.3-m Transonic Cryogenic Tunnel. Main sections include steady aerodynamic testing, unsteady aerodynamics, non-intrusive measurements, tunnel performance, and fluid mechanics. Test techniques with adequate previous documentation are briefly presented and referenced, and those for which no documentation yet exists are more thoroughly discussed. We give attention to the model building and instrumentation technology necessary for testing at high Reynolds numbers in the presence of free transition. We conclude the testing techniques thus far demonstrated in the 0.3-m TCT are on par with modern transonic tunnels, and that we can realize the specialized techniques needed to exploit the advantages of cryogenic operation.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

449. *Fuller, D. E.; and *Williams, M. S.: **Testing Experience With the National Transonic Facility**. Presented at the AIAA 14th Aerodynamic Testing Conference, West Palm Beach, Fla., March 5-7, 1986. In: Technical Papers (A86-24726), 1986, pp. 110-120, 17 refs.

AIAA Paper 86-0748 A86-24737#

The U.S. National Transonic Facility (NTF) was designed for high productivity within the constraints of operation in a cryogenic environment using nitrogen as a test gas. This environment has a significant impact on overall operation. The NTF has been operational since August 1984 and experience has been gained with respect to the facility operation and aerodynamic testing. This paper describes the experience to date with the pretest preparation and testing operations including liquid N_2 supply constraints. The instrumentation system is discussed including force, pressure, angle of attack, and model deformation measurements. Selected data from models tested in the NTF and a status of the static calibration are also presented.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

450. *Barnwell, R. W.; *Edwards, C. L. W.; *Kilgore, R. A.; and *Dress, D. A.: **Optimum Transonic Wind Tunnel.** AIAA 14th Aerodynamic Testing Conference, West Palm Beach, Fla., March 5-7, 1986. Technical Papers, pp. 173-182, 18 refs.

AIAA Paper 86-0755 A86-24743#

The optimum facility to complement existing high-Reynolds-number transonic wind tunnels is discussed. It is proposed that the facility be cryogenic, have a total pressure of 5 atm or less, and have a test section on the order of 4- to 5-meters square. The large size is to accommodate complicated models such as those used in propulsion testing. It is suggested that magnetic suspension and wall interference minimization and correction procedures be used. Simplicity of initial design is stressed as a means of providing for future growth opportunities.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

451. *Ewald, B.; and **Krenz, G.: **The Accuracy Problem of Airplane Development Force Testing in Cryogenic Wind Tunnels**. Presented at the AIAA 14th Aerodynamic Testing Conference, West Palm Beach, Fla., March 5-7, 1986. In Technical Papers (A86-24726), 1986, pp. 405-415, 3 refs.

AIAA Paper 86-0776 A86-24765#

The measurement accuracy attainable in wind-tunnel testing is limited by tunnel-flow quality, model quality, and balance accuracy. It is noted that considerable accuracy improvements are obtainable through the use of large wind-tunnel models and careful adaptation of the balance ranges to the test requirements. The primary uncertainty in balance measurements is due to thermal effects in the balance that are considerably exacerbated by cryogenic wind-tunnel conditions. Attention is given to cryogenic balance development efforts aimed at the avoidance of temperature gradients in the balance structure.

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**Messerschmitt-Bölkow-Blohm GmbH–Bremen, Postfach 107845, D-2800 Bremen 1, FRG

452. *Boyles, G. B., Jr.: **Description and Operational Status of the National Facility Computer Complex**. Presented at the AIAA 14th Aerodynamic Testing Conference, West Palm Beach, Fla. March 5-7, 1986. In: Technical Papers (A86-24726), 1986, pp. 369-374, 3 refs.

AIAA Paper 86-0783 A86-24761#

This paper describes the U.S. National Transonic Facility (NTF) computer complex and its support of tunnel operations. The capabilities of the research data acquisition and reduction are discussed along with the types of data that can be acquired and presented. Pretest, test, and post-test capabilities are also outlined along with a discussion of the computer complex to monitor the tunnel-control processes and provide the tunnel operators with information needed to control the tunnel. Planned improvements to the computer complex for support of future testing are presented.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

453. *Esch, P.; and **Gross, U.: **Design and Construction of a Cryogenic-Wind-Tunnel Model**. Rep. DCAF-A07087, Paper presented at Statusseminar Ober Luftfahrtforschung und Luftfahrttechnologie, Munich, Germany, April 28-30, 1986, 42 pp., 10 refs., in German.

A87-13988#

This paper reviews the status of efforts to design and build a 1:10-scale model of the TST, an experimental Alpha-Jet aircraft with transonic wing, for use in both conventional and cryogenic wind tunnels. Consideration is given to the choice of scale, the simulation of the TST flight envelope, the model load and its implications for the balance measurement range, the strength properties of the martensitically-hardenable 18 Ni 1700 steel selected for the model, and the model instrumentation.

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**Messerschmitt-Bölkow-Blohm GmbH–Ottobrunn, Postfach 801220, D-8000 Ottobrunn, FRG

454. *Maurer, F.: **Status Report on the European Transonic Wind Tunnel (ETW) (Statusbericht zum EuropLischen Transschall-Windkanal/ETW)**. Presented at BMFT, Statusseminar Ober Luftfahrtforschung und Luftfahrttechnologie, Munich, Germany, April 28-30, 1986, 42 pp., 10 refs, in German.

A87-14023#

The development of ETW during phases 2.2 (the functional-design phase begun in Fall 1985) and 3 (the construction phase, still dependent on approval by the participating governments) is discussed in a status report. The emphases are on the new ETW organizational structure and on changes adopted in the ETW specifications. Topics examined include the duties of the industry architect in phases 2.2 and 3, the overall advantages and disadvantages of external insulation (EI) and internal insulation (II), two proposed II systems, EI/II cost comparisons, breathable atmospheres and breathing devices, the adjustable diffuser, and the temperature conditioning of models.

*European Transonic Windtunnel GmbH–Köln 90, Linder Höhe, D-5000 Köln 90, FRG

455. *Lawaczeck, O.: **DFVLR Cryogenic – Wind-Tunnel and Model Technology**. (Kryo-Windkanal-und Modelitechnik in der DFVLR). Presented at BMFT, Statusseminar Ober Luftfahrtforschung und Luftfahrttechnologie, Munich, Germany, April 28-30, 1986, 49 pp., 36 refs., in German.

A87-14024#

Projects under way in the framework of DFVLR programs on cryogenic wind-tunnel technology, new methods in applied fluid mechanics, and separated flows are surveyed, with a focus on the status of facilities and results applicable to the planned European Transonic Windtunnel (ETW). Topics examined include high-Reynolds-number airfoil measurements at ambient and cryogenic temperatures, the DFVLR cryogenic tunnels at Göttingen and Köln, measurements on the ETW test rig, and experiments on droplet evaporation and condensation. Photographs, graphs, diagrams, drawings, and tables are provided.

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456. *Daryabeigi, K.; *Ash, R. L.; and **Dillon-Townes, L. A.: **Thermal Sensing of Cryogenic Wind Tunnel Model Surfaces - Evaluation of Silicon Diodes**. Presented at the ISA 32nd International Instrumentation Symposium, Seattle, Wash., May 5-8, 1986. In: Proceedings (A87-45101), Research Triangle Park, N.C., Instrument Society of America, 1986, pp. 203-217, 16 refs.

A86-37069#
A87-45111# (Proceedings)

Different sensors and installation techniques for surface temperature measurement of cryogenic wind-tunnel models were studied. Silicon diodes were selected for further consideration because of their good inherent accuracy. Their average absolute temperature deviation in comparison tests with standard platinum-resistance thermometers was 0.2 K in the range from 125 to 273 K. Subsurface temperature measurement was selected as the installation technique to minimize aerodynamic interference. Temperature distortion caused by an embedded silicon diode was studied numerically.

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**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
Contract NAS1-17099

457. *Supplee, F. H., Jr.; and *Tcheng, P.: **A Miniature Remote Deadweight Calibrator.** Presented at the 32nd International Instrumentation Symposium, Seattle, Wash., May 5-8, 1986. In: Proceedings (A87-45101) Instrument Society of America, 1986, pp. 65-85.

A87-45104#

A miniature, computer-controlled, deadweight calibrator was developed to remotely calibrate a force transducer mounted in a cryogenic chamber. This simple mechanism allows automatic loading and unloading of deadweights placed onto a skin-friction balance during calibrations. Equipment for the calibrator includes a specially designed set of five interlocking 200-milligram weights, a motorized lifting platform, and a controller box taking commands from a microcomputer on an IEEE interface. The computer is also used to record and reduce the calibration data and control other calibration parameters. The full-scale load for this device is 1,000 milligrams; however, the concept can be extended to accommodate other calibration ranges.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

458. *Lawing, P. L.; *Kilgore, R. A.; and *McGuire, P. D.: **Cryogenic Wind Tunnels for High Reynolds Number Testing.** NASA TM-87743, May 1986, 94 pp., 36 refs.

N86-29872#

This paper is a compilation of lectures presented at various universities over a span of several years. A central theme of these lectures has been to present the research facility in terms of the service it provides to, and its potential effect on the entire community, rather than just the research community. This theme is preserved in this paper which deals with the cryogenic transonic wind tunnels at the NASA Langley Research Center. Transonic aerodynamics is a focus both because of its crucial role in determining the success of aeronautical systems and because cryogenic wind tunnels are especially applicable to the transonic problem. The paper also provides historical perspective and technical background for cryogenic tunnels, culminating in a brief review of cryogenic wind-tunnel projects around the world. An appendix is included to provide up-to-date information on testing techniques developed for the cryogenic tunnels at NASA Langley Research Center. To be as inclusive and as current as possible, the appendix is less formal than the main body of the paper. It is anticipated this paper will be of particular value to the technical layman inquisitive as to the value of, and need for, cryogenic tunnels.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

459. *Johnson, C. B.; and *Stainback, P. C.: **Dynamic Measurement of Total Temperature, Pressure, and Velocity in the Langley 0.3-Meter Transonic Cryogenic Tunnel.** NASA TP-2584, May 1986, 45 pp., 13 refs.

N86-24709#

There is theoretical and experimental evidence which indicates a sudden or step change in the rate at which the liquid nitrogen is injected into the circuit of a cryogenic wind tunnel can cause a temperature front in the flow for several tunnel circuit times. A temperature front, which occurs at intervals equal to the circuit time, is a sudden increase or decrease in the temperature of the flow followed by a nearly constant temperature. Since these fronts can have an effect on the control of the tunnel as well as the time required to establish steady flow conditions in the test section of a cryogenic wind tunnel, tests were made in the settling chamber in the NASA Langley 0.3-meter Transonic Cryogenic Tunnel (0.3-m TCT) in which high-response instrumentation was used to measure the possible existence of these temperature fronts. Three different techniques were used to suddenly change the rate of liquid nitrogen being injected into the tunnel and the results from these three types of tests showed that temperature fronts do not appear to be present in the 0.3-m TCT. Also included are the velocity and pressure fluctuations measured in the settling chamber downstream of the screens and the associated power spectra.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

460. *Ferris, A. T.: **Cryogenic Strain Gage Techniques Used in Force Balance Design for the National Transonic Facility.** NASA TM-87712, May 1986, 15 pp., 3 refs.

N86-27618#

A force balance is a strain-gage transducer used in wind tunnels to measure the forces and moments on aerodynamic models. Techniques have been established for temperature-compensation of force balances to allow their use over the operating temperature range of a cryogenic wind tunnel (-190 to 60 °C) without thermal control. This was done by using a patented strain-gage matching process to minimize inherent thermal differences and a thermal compensation procedure to reduce the remaining thermally-induced outputs to acceptable levels. A method of compensating for mechanical movement of the axial force measuring beam caused by thermally-induced stresses under transient temperatures is also included.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

461. *Selby, G. V.: **Vapor-Screen Flow-Visualization Experiments in the NASA Langley 0.3-m Transonic Cryogenic Tunnel - Final Report.** NASA CR-3984, May 1986, 38 pp., 16 refs.

N86-24661#

The vortical flow on the leeward side of a delta-wing model has been visualized at several different tunnel conditions in the NASA Langley 0.3-meter Transonic Cryogenic Tunnel using a vapor-screen flow-visualization technique. Vapor-screen photographs of the flow field are presented and interpreted relative to phenomenological implications. Results show that the use of nitrogen fog in conjunction with the vapor-screen technique is feasible.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.
Contract NGT-47-003-029

462. *Faulmann, D.: **Cryogenic Wind Tunnels. Problems of Continuous Operation at Low Temperatures.** Translation into English of "Souffleries Cryogeniques Problemes Lies au Fonctionnement Continue en Basse Temperature," Rep. DERAT-9/5007-DY; OA-9/5007-AYD, June 1980, 53 pp. Translated by Kanner (Leo) Associates, Redwood City, Calif. NASA TM-88446, June 1986, 52 pp., 7 refs.

N86-28099#

Note: For the original French report see citation no. [213] in this bibliography.

The design of a cryogenic wind tunnel which operates continuously and is capable of attaining transonic speeds at generating pressures of about 3 bars is described. Its stainless steel construction with inside insulation allows for very rapid temperature variations promoted by rapid changes in the liquid nitrogen flow. A comparative study of temperature measuring probes shows a good reliability of thin-film thermocouples. To measure fluctuations, only a cold wire makes is possible to record frequencies of about 300 Hz. The use of an integral computer method makes it possible to determine the impact of the wall temperature ratio to the adiabatic wall temperature for the various parameters characterizing the boundary layer. These cases are processed with positive- and negative-pressure gradients.

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Contract NASw-4005 (for translation)

463. *Blanchard, A.; *Delcourt, V.; and *Plazanet, M.: **Problems Associated With Operations and Measurement in Cryogenic Wind Tunnels**. Translation into English of "Problemes Lies au Fonctionnement et aux Mesures en Soufflerie Cryogenique" Rep. OA-13/5007-AYD DERAT-13/5007-DY, July 1981. Translated by Scientific Translation Service, Santa Barbara, Calif. NASA TM-88443, June 1986, 75 pp., 6 refs.

N86-28100#

Note: For original French report see citation no. [248] in this bibliography.

Cryogenic wind tunnel T'3 at ONERA/CERT, a continuous fan-driven tunnel, has been the object of improvements and the installation of auxiliary equipment, dealing in particular with the enlargement of the liquid nitrogen injection reservoir and the hook-up to a fast-data acquisition system. Following a brief description of the installation and its functioning, the main experimental techniques and the instrumentation used in the cryogenic environment are presented.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France
Contract NASw-4004 (for translation)

464. *Kraft, D.: **Optimal Control: A Systematic Aid for the Computer Aided Exploration of the Dynamic Possibilities of a Cryogenic Wind Tunnel.** Ph.D. Thesis - Ruhr Univ. DFVLR-FB-86-23; ETN-86-98188, June 1986, 215 pp., 183 refs., in German.

N87-10879#

Note: For an English translation of this thesis see citation no. [484] in this bibliography.

The dynamic systems behavior of a cryogenic wind tunnel was analyzed for an automatic control system which meets the stringent safety requirements and operating specifications in a wide domain of operation. For cost, safety, and availability reasons this analysis cannot be performed on the real tunnel, but must be conducted on a mathematical model. The dynamic behavior of the wind tunnel is characterized by strongly coupled nonlinear differential equations; therefore optimal control was applied for analysis. The boundary values of the system are the basis of comparison for the different steps of the analysis, while the control and state constraint and their variations resulting from the operating specifications represent systematic step sizes along which the dynamic spectrum was explored. This procedure yields statements about the robustness of nonlinear systems. Direct numerical methods for the solution of optimal control problems are described.

*DFVLR–Wessling/Obb., Oberpfaffenhofen, D-8031 Wessling/Obb., FRG

465. *Hoenlinger, H.; and *Sensburg, O.: **Aeroelastic Models in Aircraft Design.** Rept. MBB/LKE-294/S/PUB/249; ETN-88-9-91439; DCAF E070087, June 1986, 10 pp., in German.

N88-20298#

The use of aeroelastic model tests in aircraft design is outlined. Aeroelastic models are economical for the development and testing of novel active-control technologies and measuring methods for aircraft vibration tests. The linearized dynamic calculation model of a flying elastic aircraft was realized in a wind tunnel using aeroelastic models. The validity domain of an aeroelastic model was substantially extended in a cryogenic wind tunnel.

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466. *Daryabeigi, K.; and *Ash, R. L.: **Thermal Sensing of Cryogenic Wind Tunnel Model Surfaces Final Report 15 May 1984 - 28 February 1985.** NASA CR-178136, July 1986, 56 pp., 38 refs.

N86-30098#

Different sensors and installation techniques for surface temperature measurement of cryogenic wind-tunnel models were studied. Silicon diodes were selected for further consideration because of their good inherent accuracy (their average absolute temperature deviation in comparison tests with standard platinum resistance thermometers was 0.2 K in the range from 125 to 273 K). Subsurface temperature measurement was selected as the installation technique to minimize aerodynamic interference. Temperature distortion caused by an embedded silicon diode was studied numerically.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.
Contract NAS1-17099

467. *Snow, W. L.; *Burner, A. W.; and *Goad, W. K.: **Improvement in the Quality of Flow Visualization in the Langley 0.3-Meter Transonic Cryogenic Tunnel.** NASA TM-87730, August 1986, 24 pp., 4 refs.

N86-28389#

Optical diagnostic techniques have not been as successful in the 0.3-meter Transonic Cryogenic Tunnel as in conventional wind tunnels. This paper describes a simple shadowgraph experiment which allowed evacuation of the optical paths outside the test section. The results show that refractive index variations induced by temperature gradients outside the test section account for most of the image degradation. Earlier reports had erroneously attributed this degradation to inhomogeneities in the test section. Evacuation of the paths leading to and from the test section significantly improves the quality of flow visualization.

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468. *Rallo, R. A.; *Dress, D. A.; and *Siegle, H. J. A.: **Operating Envelope Charts for the Langley 0.3-Meter Transonic Cryogenic Wind Tunnel.** NASA TM-89008, August 1986, 23 pp., 9 refs.

N86-31595#

To take full advantage of the unique Reynolds number capabilities of the 0.3-meter Transonic Cryogenic Tunnel (0.3-m TCT) at the NASA Langley Research Center, it was designed to accommodate test sections other than the original, octagonal, three-dimensional test section. A 20- by 60-cm two-dimensional test section was installed in 1976 and was extensively used, primarily for airfoil testing, through the fall of 1984. The tunnel was inactive during 1985 so a new test section and improved high-speed diffuser could be installed in the tunnel circuit. The new test section has solid adaptive top and bottom walls to reduce or eliminate wall interference for two-dimensional testing. The test section is 33- by 33-cm in cross section at the entrance and 142 cm long. In the planning and running of past airfoil tests in the 0.3-m TCT, the use of operating envelope charts have proven very useful. These charts give the variation of total temperature and pressure with Mach number and Reynolds number. The operating total temperature range of the 0.3-m TCT is from about 78 to 327 K with total pressures ranging from about 17.5 to 88 psia. This report presents the operating envelope charts for the 0.3-m TCT with the adaptive wall test section installed. They were all generated based on a 1-foot chord model. The Mach numbers vary from 0.1 to 0.95.

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469. *Takashima, K.; *Sawada, H.; *Aoki, T.; and *Kayaba, S.: **Trial Manufacture of NAL 0.1 m × 0.1 m Transonic Cryogenic Wind Tunnel.** NAL TR-910, (Technical Report of National Aerospace Laboratory), August 1986, 57 pp., in Japanese.

ISSN 0389-4010 N87-21969#
U.D.C. 533.6.071

To study the cryogenic wind tunnel, in which high-Reynolds-number tests can be made, a small transonic cryogenic wind tunnel was constructed. The construction and the operational results are described in this paper. This small cryogenic wind tunnel, with a test section of 0.1 × 0.1 m, was built to ascertain the basic design specifications for a large transonic cryogenic wind tunnel which will be constructed in the future, and also to gain skill in operating the cryogenic wind tunnel. The capability of this wind tunnel is from ambient temperature down to -173 °C, for Mach numbers ranging from 0.4 to 1.02, and for a unit Reynolds number up to 1.3 million per cm with more than one hour running time. In this paper, the design concept is first briefly given, then the complete system, that is, the wind tunnel, the liquid nitrogen supply system, the gaseous nitrogen exhaust system, the thermal insulation, the fan and the drive motor, and the instrumentation and operating system, are described in detail. Finally, the experimental results are discussed. The conclusion is that cryogenic wind-tunnel operation can be safely and successfully conducted.

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470. *Heinzerling, W.: **Der zukünftige Einsatz des Europäischen Transschall-Windkanals ETW bei der Entwicklung fortschrittlicher Flugzeuge.** (The future use of the European Transonic Wind Tunnel ETW in the development of advanced aircraft). In: Yearbook 1986 II; DGLR, Annual Meeting, Munich, Germany, October 8-10, 1986, Reports (A87-48154 21-01). Bonn, Deutsche Gesellschaft für Luft-und Raumfahrt, 1986, pp. 700-711, 18 refs., in German.

DGLR Paper 86-140 A87-48162

*Messerschmitt-Bölkow-Blohm GmbH–Ottobrunn, Postfach 801220, D-8000 Ottobrunn, FRG

471. *Johnson, C. B.; *Johnson, W. G., Jr.; and *Stainback, P. C.: **A Summary of Reynolds Number Effects on Some Recent Tests in the Langley 0.3-Meter Transonic Cryogenic Tunnel.** Presented at the SAE, Aerospace Technology Conference and Exposition, Long Beach, Calif., October 13-16, 1986, 17 pp., 44 refs.

SAE Paper 861765 A87-32626

Reynolds number effects noted from selected test programs conducted in the NASA Langley 0.3-Meter Transonic Cryogenic Tunnel (0.3-m TCT) are discussed. The tests, which cover a unit Reynolds number range from about 2.0 to 80.0 million per foot, summarize effects of Reynolds number on (1) aerodynamic data from a supercritical airfoil, (2) results from several wall-interference correction techniques, and (3) results obtained from advanced, cryogenic test techniques. The test techniques include 1) use of a cryogenic sidewall-boundary-layer removal system, 2) detailed pressure and hot-wire measurements to determine test-section flow quality, and 3) use of a new hot-film system suitable for transition detection in a cryogenic wind tunnel. The results indicate that Reynolds number effects appear most significant when boundary-layer-transition effects are present and at high lift conditions when boundary-layer separation exists on both the model and the tunnel sidewall.

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472. *Seraudie, A.; *Blanchard, A.; and *Dor, J.-B.: **Description of Tests Run in the T2 Cryogenic Wind Tunnel.** Presented at the Association Aeronautique et Astronautique de France, Colloque d' Aerodynamique, 23rd, Modane, France, November 12-14, 1986, 44 pp., 19 refs., in French.

AAAF Paper NT 86-07 A87-38033#

Note: For an English translation of this report see citation no. [474] in this bibliography.

This paper describes test methods and measurement techniques of the high-Reynolds-number (up to 30 million), high-pressure, cryogenic T2 wind tunnel. Velocity and pressure fluctuation measurements are obtained with high-bandpass pressure probes and hot-film probes. Stagnation and static pressure probes with short response times are used to study wakes. Unsteady static-pressure measurements, using sensors placed at the profile boundary, are obtained to study buffeting. Transition positions are detected using IR thermography, stagnation-pressure and longitudinal sounding, thermocouple measurements of boundary temperatures, and oil-film parietal visualizations. The measurement of aerodynamic coefficients of a model using a five-component balance is also discussed.

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473. *Johnson, C. B.; **Murthy, A. V.; and *Ray, E. J.: **A Description of the Active and Passive Sidewall-Boundary-Layer Removal Systems of the 0.3-Meter Transonic Cryogenic Tunnel.** NASA TM-87764, November 1986, 21 pp., 11 refs.

N87-11801#

Results are presented for an operational checkout and shakedown of the active sidewall-boundary-layer removal system recently installed in the NASA Langley 0.3-meter Transonic Cryogenic Tunnel (0.3-m TCT). Prior to the installation of this active removal system, the sidewall-boundary layer was removed passively by exhausting directly to the atmosphere (i.e., no reinjection). With the active removal system using the reinjection compressor, the removal capability is greatly expanded to cover the entire operating envelope of the 0.3-m TCT. Details of the active removal system are presented including the compressor reinjection circuit, the compressor pressure ratio/surge control, and the compressor recirculation loop. The control logic and features of the compressor surge control are explained. Initial tests, covering critical operating conditions, show mass flow removal rates of about 5 percent can be obtained at lower Mach numbers with the active system. Measured performance characteristics of the compressor are presented. As part of the validation of the active system, limited airfoil tests were made using the new system.

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474. *Seraudie, A.; *Blanchard, A.; and *Dor, J.-B.: **Description of Tests Run in the T2 Cryogenic Wind Tunnel.** Rept. PB87-170296; and NOTE-TECHNIQUE-86-07; November 1986, 51 pp., 19 refs., in English.

ISBN-2-7170-0855-1 N88-16672#

Note: For the original form of this report see citation no. [472] in this bibliography.

Research done on the testing techniques and measurement methods to be used in the T2 pressurized cryogenic wind tunnel is described. It was found that the model temperature must be established before measuring the gust. Several rounds of cryogenic tests provided valuable experience in conducting cold flow measurements. Cross checking was done to validate the tests. However, some experimental snags related to high-unit Reynolds numbers were encountered during natural transition tests. It was found to be necessary to take the level of flow turbulence into account and to improve the condition of the model surface to maintain a laminar state in the boundary layers of most of the airfoils.

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475. *Cole, S. R.: **Exploratory Flutter Test in a Cryogenic Wind Tunnel.** Journal of Aircraft, vol. 23, December 1986, pp. 904-911, 9 refs.

Note: For earlier forms of this report and an abstract see citation nos. [402 and 404] in this bibliography.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

476. *Zacharias, A.: **European Transonic Wind Tunnel (ETW) Model Technology. Investigations of the Transient Temperature and Stress Behavior of ETW Models.** MBB-LKE-123/S/PUB-242; ETN-87-98972; DCAF E070087, 1986, 46 pp., 3 refs., in German.

N87-17721#

The results of experimental and theoretical studies of the transient temperature and stress behavior of models under European Transonic Wind Tunnel (ETW) conditions are presented. The cryogenic wind-tunnel technology imposes high materials requirements. The applied measurement techniques require further software and hardware developments. The conditioning of the model before the measurements has to be performed with a well-balanced speed in order to avoid high stresses. The ETW operation for commercial-development measurements involves substantial risks. The fundamentals and proposals for the construction and handling of models in the ETW are presented.

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477. ***Aircraft and Engine Development Testing.** TLSP: Final Report, 1984-1985, Committee on Aircraft and Engine Development Testing, 1986, 81 pp., 17 refs., in German.

AD-A176711 N87-20961#

This report is a study of the use, timing, and costs of development testing in the new aeronautical test facilities: the Aeropropulsion Systems Test Facility (ASTF), the U.S. National Transonic Facility (NTF), and the 80- by 120-Foot low-speed tunnel at NASA-Ames Research Center, California.

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478. *Johnson, C. B.; *Carraway, D. L.; *Stainback, P. C.; and **Fancher, M. F.: **A Transition Detection Study Using a Cryogenic Hot Film System in the Langley 0.3-Meter Transonic Cryogenic Tunnel.** Presented at the 25th AIAA Aerospace Sciences Meeting, Reno, Nev., January 12-15, 1987, 23 pp., 25 refs.

AIAA-87-0049 A87-22380#

Note: For later papers on this work see citation nos. [481 and 489] in this bibliography.

A transition detection study was made in the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) using a specialized hot-film system designed specifically for use in cryogenic wind tunnels. Quantitative transition location data obtained at near cryogenic conditions, represent the first definitive transition Reynolds numbers obtained in a cryogenic wind tunnel. The model was tested at both adiabatic and nonadiabatic wall conditions with a wall-to-total temperature ratio as low as 0.47. Test results indicate an improved technique for hot-film installation and a modified data acquisition system would allow the on-line determination of the location of boundary layer transition in cryogenic wind tunnels, such as the U.S. National Transonic Facility.

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479. *Hess, R. A.; *Seidel, D. A.; *Igoe, W. B.; and *Lawing, P. L.: **Highlights of Unsteady Pressure Tests on a 14 Percent Supercritical Airfoil at High Reynolds Number, Transonic Condition.** NASA TM-89080, Corrected copy, January 1987, 18 pp., 12 refs.

N87-17667#

Steady and unsteady pressures were measured on a 2-D supercritical airfoil in the NASA Langley 0.3-m Transonic Cryogenic Tunnel at Reynolds numbers from 6 to 35 million. The airfoil was oscillated in pitch at amplitudes from 0.25 to 1.0 degrees and at frequencies from 5 Hz to 60 Hz. This paper discusses the special requirements of testing an unsteady pressure model in a pressurized cryogenic tunnel. Selected steady measured data are presented and compared with GRUMFOIL calculations at Reynolds numbers of 6 and 30 million. Experimental unsteady results at Reynolds numbers of 6 and 30 million are examined for Reynolds number effects. Measured unsteady results at two mean angles of attack at a Reynolds number of 30 million are also examined.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

480. *Sawada, H.: **Heated External Balance for Cryogenic Wind Tunnel.** In: NAL News, no. 333, January 1987, pp. 2-3, in Japanese.

ISSN 0023-2726

This paper describes a heated external balance used with the 0.1 × 0.1 m Transonic Cryogenic Wind Tunnel at the National Aerospace Laboratory (NAL). It also describes tests of a 30 mm span AGARD-B model at cryogenic temperatures using the heated balance. The results show the heated balance works well.

*National Aerospace Laboratory, 7-44-1 Jindaiji-machi Chofu-shi, Tokyo 182, Japan

481. *Johnson, C. B.; *Carraway, D. L.; *Stainback, P. C.; and **Fancher, M. F.: **Hot-Film System for Transition Detection in Cryogenic Wind Tunnels.** In: Research in Natural Laminar Flow and Laminar-Flow Control, Part 2 of a symposium held at NASA Langley Research Center, Hampton, VA March 16-18, 1987, (N90-12519#), December 1987, pp. 358-376.

N90-12522#

Note: For other papers on this work, see citation nos. [478 and 489] in this bibliography.

It is well known that the determination of the location of boundary-layer transition is necessary for the correct interpretation of aerodynamic data in transonic wind tunnels. In the late 1970s the Douglas Aircraft Company developed a vapor deposition hot-film system for transition detection in cryogenic wind tunnels. Tests of the hot-films in a low-speed tunnel demonstrated the ability to obtain on-line transition data with an enhanced simultaneous hot-film data acquisition system. The equipment design and specifications are described.

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**Douglas Aircraft Co., McDonnell Douglas Corp., 3855 Lakewood Blvd., Long Beach, CA 90846 U.S.A.

482. *Lawing, P. L.; **Vakili, A. D.; and **Wu, J. M.: **Recent Tests at Langley With a University of Tennessee Space Institute (UTSI) Skin Friction Balance.** In: Research in Natural Laminar-Flow Control, Part 2 of a Symposium held at NASA Langley Research Center, Hampton, VA March 16-19, 1987, (N90-12519#), pp. 407-411.

N90-12527#

The experience at NASA Langley Research Center with the University of Tennessee Space Institute skin-friction balances is summarized. The Karman-Schoenherr flat-plate skin-friction formulation is included for comparison. It is concluded that the balance is capable of operation in environments as diverse as cryogenic, transonic, high-shear rate of the 0.3 meter Transonic Cryogenic Tunnel, and high-temperature supersonic environment of the Unitary Plan Wind Tunnel. Proposed new research is outlined.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
**University of Tennessee Space Institute, Tullahoma, TN 37388 U.S.A.

483. *Snow, W. L.; *Burner, A. W.; and *Goad, W. K.: **Recent Flow Visualization Studies in the 0.3-m TCT.** In: Research in Natural Laminar Flow and Laminar-Flow Control, Part 2 of a symposium held at NASA Langley Research Center, Hampton, Va., March 16-19, 1987, (N90-12519#), pp. 412-419, 43 refs.

N90-12528#

Light beams are altered by refractive index changes; flow-induced refractive index changes provide the impetus for conventional visualization techniques such as schlieren and shadowgraph. Unfortunately effects related to the flow can be masked by refractive index inhomogeneities external to the test section. A simple shadowgraph scheme was used to assess the flow quality of the NASA Langley 0.3 meter Transonic Cryogenic Tunnel. When the penetration tubes were evacuated the quality of the shadowgraph improved dramatically.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

484. *Kraft, D.: **Optimal Control: A Systematic Device for the Computer-Aided Exploration of the Dynamic Possibilities of a Cryogenic Wind Tunnel.** ESA-TT-1016, March 1987, 228 pp., 183 refs., (Translation into English of the German report DFVLR-FB-86-23, ETN-87-90014.) The original language document is available from DLR, Cologne, Germany.

N87-27676#

Note: The original German report is citation no. [464] in this bibliography.

The dynamic systems behavior of a cryogenic wind tunnel was analyzed for an automatic control system which meets the safety requirements and operating specifications in a wide domain of operations. For cost, safety, and availability reasons this analysis cannot be performed on the real tunnel, but must be made using a mathematical model. The dynamic behavior of the wind tunnel is characterized by strongly coupled nonlinear differential equations; therefore optimal control was applied for analysis. The boundary values of the system are the basis of comparison for the different steps of the analysis, while the control and state constraint and their variations resulting from the operating specifications represent systematic step sizes along which the dynamic spectrum was explored. This procedure yields statements about the robustness of nonlinear systems. Direct numerical methods for the solution of optimal-control problems are described. ESA

*DFVLR–Wessling/Obb., Oberpfaffenhofen, D-8031 Wessling/Obb., FRG

485. *Gobert, J. L.; and *Breil, J. F.: **Preliminary Study of an Apparatus to Control the Temperature of the Flow Entering the T2 Cryogenic Wind Tunnel.** March 1987, 40 pp. Translation into English by Leo Kanner Associates, Redwood City, Calif. of "Etude preliminaire d'un dispotif de controle de la temperature de l'ecoulement destine a la soufflerie cryogenique T2." ONERA-CERT R.T. OA 20/5007, April 1983, 37 pp., 6 refs.

N87-26052#

Note: For the original French report see citation no. [334] in this bibliography.

The use of intermittent cryogenic wind tunnels reveals the need for controlling the flow parameters: temperature, pressure, and speed. This report gives the results of a preliminary study made in the

CERT T'2 wind tunnel. Its purpose is to show the feasibility of controlling the temperature with a real-time mini-computer.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France
Contract NASw-4005 (for translation)

486. *Boyden, R. P.; *Ferris, A. T.; *Johnson, W. G., Jr.; *Dress, D. A.; and *Hill, A. S.: **Aerodynamic Measurements and Thermal Tests of a Strain-Gage Balance in a Cryogenic Wind Tunnel.** NASA TM-89039, April 1987, 85 pp., 22 refs.

N87-20517#

An internal strain-gage balance designed and built in Europe for use in cryogenic wind tunnels has been tested in the NASA Langley 0.3-meter Transonic Cryogenic Tunnel. A sharp-leading-edge delta-wing model was used to provide the aerodynamic loading for these tests. Part of the evaluation was made at equilibrium balance temperatures. It consisted of comparing the data taken at a tunnel stagnation temperature of 300 K with the data taken at 200 and 110 K while maintaining either the Reynolds number or the stagnation pressure constant. Results obtained with the balance during the force tests were found to be accurate and repeatable both with and without the use of a convection shield on the balance. An additional part of this evaluation involved obtaining data on the transient temperature response of the balance during both normal and rapid changes in the tunnel stagnation temperature. The variation of the temperature with time was measured at three locations on the balance near the physical locations of the strain gages. The use of a convection shield significantly increased the time required for the balance to stabilize at a new temperature during the temperature response tests.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

487. *McIntosh, G. E.; *Lombard, D. S.; *Martindale, D. L.; and *Dunn, R. P.: **Cost Effective Use of Liquid Nitrogen in Cryogenic Wind Tunnels–Final Report.** NASA CR-178279, April 1987, 62 pp., 4 refs.

N87-23663#

This paper proposes a method of reliquefying from 12 to 19 percent of the nitrogen exhaust gas from a cryogenic wind tunnel. Technical feasibility and cost effectiveness of the method depends on the performance of an innovative positive displacement expander which requires scale model testing to confirm design studies. In addition, the existing cryogenic system at the 0.3-m Transonic Cryogenic Tunnel has been surveyed and extensive upgrades are proposed. Upgrades are generally cost effective and may be done immediately since they are based on established technology.

*CRYOLAB, INC., 4175 Santa Fe Road, San Luis Obispo, CA 93401 U.S.A.
Contract NAS1-18216

488. *Blocher, R.; and *Weiss, E.: **Design Study - Manipulator Systems for Model Handling in European Transonic Windtunnel.** (Konzeptstudie, Manipulatorsystem für Modelhandhabung im Europaeischen Transschall-Windkanal), ETN-88-91944, May 25, 1987, 199 pp., in German.

N88-24651#

Electrical master-slave manipulators in cryogenic temperatures and under pressure are proposed for remote model handling. Economy of time and energy can be achieved without thermal stresses in model and wind tunnel. Manipulator design consists of two arms and seven degrees of freedom. Control is achieved by frequency-regulated asynchronous motors. Digital electronics procures total automation for the study of collision protection and special handling cycles. Viewing and associated audio-systems are provided by stereo and monosystems giving an optimal global view of the operating field. Mechanical properties of construction parts in a cryogenic environment are studied. ESA

*Blocher-Motor, GmbH and Co. K.G., Metzingen, FRG

489. *Johnson, C. B.; *Carraway, D. L.; *Tran, S. Q.; and *Hopson, P., Jr.: **Status of a Specialized Boundary Layer Transition Detection System for Use in the U.S. National Transonic Facility.** In: ICIASF '87 – International Congress on Instrumentation in Aerospace Simulation Facilities, 12th, Williamsburg, Va., June 22-25, 1987, Record (A88-36483). New York, Institute of Electrical and Electronics Engineers, Inc., 1987, pp. 141-155, 15 refs.

A88-36500#

Note: For other papers on this subject see citation nos. [478 and 481] in this bibliography.

The Douglas Aircraft Company developed a hot-film system for transition detection in cryogenic tunnels in the late 1970s. The Douglas system was tested and evaluated in the NASA Langley 0.3-meter Transonic Cryogenic Tunnel (TCT). Although a significant amount of transition data was obtained, the original goal of on-line detection of transition was not achieved. Since the tests in the TCT, researchers at NASA Langley have developed an improved deposition technique for cryogenic hot films. The new technique includes a new dielectric and a new technique for the build-up of the hot-film substrate. Tests of the new hot films in a low-speed tunnel demonstrated the ability to obtain on-line transition data. The tests also demonstrated an improved hot-film data acquisition system. A comparison of data from the new system with stability theory demonstrates the detection of Tollmien-Schlicting waves at transition onset.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

490. *Rao, M. G.; and *Scurlock, R. G.: **A Silicon Diode Thermometer, With Integrated Circuit Instrumentation Package, for Operation Between 77.5 K and 290 K.** In: ICIASF '87 - International Congress on Instrumentation in Aerospace Simulation Facilities, 12th, Williamsburg, Va., June 22-25, 1987, Record (A88-36483 14-35). New York, Institute of Electrical and Electronics Engineers, Inc., 1987, pp. 92-94, 5 refs.

A88-36492

The use of cold electronic systems for processing transducer signals is studied. In particular, this paper describes the development of a single-channel cold electronic system interfacing with a silicon diode thermometer in which the whole instrumentation package operates at any temperature between 77.5 and 290 K. The electronic system includes a constant current source, signal conditioning amplifiers, and a 12-bit A/D converter. The thermometer package has a resolution of 0.2 K and an absolute accuracy of 0.5 K.

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Research supported by the Department of Trade and Industry

491. *Burner, A. W.; *Snow, W. L.; *Goad, W. K.; and *Childers, B. A.: **A Digital Video Model Deformation System.** In: ICIASF '87 - International Congress on Instrumentation in Aerospace Simulation Facilities, 12th, Williamsburg, Va., June 22-25, 1987, Record (88-36483 14-35). New York, Institute of Electrical and Electronics Engineers, Inc., 1987, pp. 210-220, 13 refs.

A88-36508#

This paper discusses the use of solid-state array cameras and a microcomputer-controlled image acquisition system to measure model deformation in a wind tunnel. This digital system improves an earlier video model deformation system that used high-resolution tube cameras and required the manual measurement of targets on video hardcopy images. The new system eliminates both the vibration-induced distortion associated with tube cameras and the manual readup of video images necessary in the earlier version. Camera calibration and data reduction procedures necessary to convert pixel image plane data from two cameras into wing deflections are presented. The paper also describes laboratory tests to establish the uncertainty of the system with the geometry to be used. I.E.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

492. *Selby, G. V.: **Progress in Visualizing Cryogenic Flow Using the Vapor-Screen Technique.** In: ICIASF '87 - International Congress on Instrumentation in Aerospace Simulation Facilities, 12th, Williamsburg, Va., June 22-25, 1987, Record (A88-36483 14-35). New York, Institute of Electrical and Electronics Engineers, Inc., 1987, pp. 233-238, 10 refs.

A88-36511

This paper describes the visualization of the vortical flow on the leeward side of a delta-wing model at several different tunnel conditions in the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) using a vapor-screen flow-visualization technique. Vapor-screen photographs of the subject flow field are presented and are interpreted relative to phenomenological implications. Results indicate that the use of nitrogen fog in conjunction with the vapor-screen technique is feasible.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.

493. *Ewald, B.; and **Graewe, E.: **Development of Internal Balances for Cryogenic Wind Tunnels.** In: ICIASF '87 - International Congress on Instrumentation in Aerospace Simulation Facilities, 12th, Williamsburg, Va., June 22-25, 1987, Record (A88-36483 14-35). New York, Institute of Electrical and Electronics Engineers, Inc., 1987, pp. 274-282, 13 refs.

A88-36517

The construction of large cryogenic wind tunnels will be of little benefit for aircraft development if force measurements in such tunnels are not possible with at least the same accuracy as in conventional tunnels. Up to now this target is still far away due to severe thermal effects in the strain-gage balance. This paper outlines novel approaches for two of these effects. The effect of apparent strain over the whole temperature range is minimized by a compensation of each individual gage. With respect to temperature gradients, a novel arrangement of the axial force systems allows a correct separation of thermal effect and force measurement.

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**Messerschmitt-Bölkow-Blohm GmbH–Bremen, Postfach 107845, D-2800 Bremen 1, FRG

Funded by the German Ministry of Research & Technology

494. *Sawada, H.: **Cryogenic Wind Tunnels.** In: Journal of the Japanese Society of Aeronautical and Space Sciences, vol. 35, no. 401, June 1987, pp. 285-293, 36 refs., in Japanese.

ISSN 0021-4663 A90-17346

This paper describes the 0.1 × 0.1 m Transonic Cryogenic Wind Tunnel built at the National Aerospace Laboratory (NAL) in 1982. It describes the fully automatic control system implemented using an *NEC* microcomputer. It also describes a heated external balance successfully used in tests with the tunnel at cryogenic conditions. Finally, the author presents the need for a large cryogenic transonic wind tunnel for Japan.

*National Aerospace Laboratory, 7-44-1 Jindaiji-machi Chofu-shi, Tokyo 182, Japan

495. *Lassiter, W. S.: **Plume Dispersion of the Exhaust from a Cryogenic Wind Tunnel.** NASA TM-89148, June 1987, 29 pp., 7 refs.

N87-25545#

An analytical model was developed to predict the behavior of the plume exhausting from the cryogenic U.S. National Transonic Facility. Temperature, visibility, oxygen concentration, and flow characteristics of the plume are calculated for distance downwind of the stack exhaust. Negative buoyancy of the cold plume is included in the analysis. Compared to photographic observations, the model predicts the centerline trajectory of the plume fairly accurately, but underpredicts the extent of fogging. The diffusion coefficient is revised to bring the model into better agreement with observations.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

496. *Blanchard, A.; *Seraudie, A.; *Plazanet, M.; and *Payry, M. J.: **Test of a Trial Cryogenic Balance in the ONERA T2 Wind Tunnel.** English translation of "Essai de la Balance Probatoire Cryogenique ONERA dans la Soufflerie T2." NASA-TT-20078, July 1987, 106 pp., 6 refs.

N87-24485#

Note: For the original French version of this report see citation no. [429] in this bibliography.

The three-component cryogenic balance designed and built by the ONERA Large Means Directorate, was equipped with a light alloy schematic model and tested at the end of 1984 at the T2 wind tunnel at temperatures as low as 120 K. The tests pertained to the impact of the cryogenic conditions on the behavior of extensometric bridges while cooling the balance-model system mounted in the conditioning device and during operation with models in the test section. A few tests with thermal disequilibrium between the flow and balance made it possible to confirm the proper operation in the range 120 to 300 K. These tests showed that the balance, which was well compensated thermally, may be used in T2 with and without precooling. For any thermal gradient, the analysis was always made with the same matrices and aerodynamic coefficients were obtained with the same precision.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

497. *Bonnet, J. L.; *Seraudie, A.; *Archambaud, J.-P.; and *Mignosi, A.: **Mise en Oeuvre d'une Chaine Anemometrique Laser Bi-Composantes a la Soufflerie T2.** (Implementation of a two-component laser anemometer at the T2 wind tunnel.) RTOA no. 28/5006 AND-(DERAT N° 28/5006 DN), July 1987, 34 pp., 3 refs., includes 55 figs., in French.

A series of tests for perfecting the velocity measurement with a two-component laser anemometer has been carried out on a 180 mm chord RA16SCI airfoil at the T2 wind tunnel in September 1986. Measurements have been made on boundary layers, wake, and shock probing on the upper side of the model, mainly for two Mach number values (0.6 and 0.725) at 2° angle of attack, corresponding respectively to a steady shock and to a buffeting configuration. This experimental study allowed us to test the anemometer system, to know its limitations, and to know the practical problems of its use: theoretical limitations due to the operating mode (with or without Bragg cells), the filter, the wall approach, the density gradients, and so forth. In conclusion, good velocity measurements are reliable with this laser anemometer at the T2 wind tunnel with respect to the use limitations.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

498. *Ladson, C. L.; and *Ray, E. J.: **Evolution, Calibration, and Operational Characteristics of the Two-Dimensional Test Section of the Langley 0.3-Meter Transonic Cryogenic Tunnel,** NASA TP-2749, September 1987, 170 pp., 24 refs.

N87-28570#

This paper presents a review of the development of the first cryogenic pressure tunnel, the NASA Langley 0.3-Meter Transonic Cryogenic Tunnel (TCT). Descriptions of the instrumentation, data acquisition systems, and physical features of the two-dimensional 8- by 24-in. (20.32- by 60.96-cm) and advanced 12- by 12-in. (33.02- by 33.02-cm) adaptive-wall test-section inserts of the 0.3-m TCT are included. Basic tunnel-empty Mach number distributions, stagnation temperature distributions, and power requirements are included. The Mach number capability of the tunnel is from about 0.20 to 0.90. Stagnation pressure can be varied from about 1.2 to 6.1 atm, and the stagnation temperature can be varied from about 80 to 327 K.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

499. *Ewald, B.: **Balance Accuracy and Repeatability as a Limiting Parameter in Aircraft Development - Force Measurements in Conventional and Cryogenic Wind Tunnels.** Presented at the AGARD Fluid Dynamics Panel Symposium "Aerodynamic Data Accuracy and Quality: Requirements and Capabilities in Wind Tunnel Testing," AGARD-CP-429, (N89-16846#), held in Naples, Italy, September 28 – October 1, 1987; Paper no. 27, 12 pp., 16 refs.

N89-16873#

The success of a commercial transport development is heavily influenced by the accuracy of drag measurements during the aerodynamic development in the wind tunnel. It is shown that the internal balance is one factor limiting accuracy. The accuracy standard of modern internal balances is compared to the accuracy and repeatability requirement of the aerodynamicist. The comparison with high-precision single-component load cells promises a large improvement potential in multi-component balance design and calibration. The following fields of improvement are discussed in the paper: balance design, balance material selection and treatment, calibration methods, calibration software, and thermal effects. Perfect correction of the thermal effects is the key to the successful use of cryogenic tunnels. An approach for the crucial problem of balance body distortion due to temperature gradients is demonstrated.

*Technische Hochschule Darmstadt, Karolinenplatz 5, D-6100 Darmstadt, FRG

500. *Mabey, D. G.: **Some Aspects of Aircraft Dynamic Loads Due to Flow Separation.** Presented at the 65th Meeting of the Structures and Materials Panel of AGARD, Çesme, Turkey, October 4-9, 1987. AGARD-R-750, February 1988, 33 pp.

ISBN-92-835-0445-3 N88-18588#

This AGARD paper discusses various topics associated with the study of Aircraft Dynamic Loads due to Flow Separation. Topics discussed include the need for consistent definitions of buffet and buffeting, the advantages of consistent notation for all the papers, buffeting due to wings and other components, the alleviation of buffeting, the special difficulties of flight tests, and the special advantages of buffeting measurements in cryogenic wind tunnels.

*Royal Aircraft Establishment, Bedford, Beds MK41 6AE, England

501. *Young, C. P., Jr.; and *Gloss, B. B.; Compilers: **Second Workshop on Cryogenic Wind-Tunnel Models: Design and Fabrication.** NASA CP-3010, a workshop held at NASA Langley Research Center, Hampton, Va. on November 3-5, 1987. NASA CP-3010, October 1988, 423 pp.

X89-10005#

Note: For U.S. Government Agencies and Their Contractors Only.

The second workshop on Cryogenic Wind-Tunnel Models Design and Fabrication was held November 3-5, 1987 at the NASA Langley Research Center (LaRC). The first workshop was held on May 5-9, 1982 at LaRC. Since 1982 a large number of models have been tested at full-scale Reynolds number in a cryogenic environment. Since many cryogenic models had been designed, fabricated, tested in the NTF and the LaRC 0.3-meter Transonic Cryogenic Tunnel, and significant advances in cryogenic model technology had been made, it was appropriate that a second workshop be held. Also, the experience gained in designing and fabricating cryogenic wind-tunnel models over the past 5 years exists within a large number of organizations. There was a strong need to bring this experience together and to share information among all interested parties. As a result, the workshop included representatives from government, the airframe industry, and model design and fabrication companies. Cryogenic wind-tunnel model topics addressed include design; analysis, test, and development; fabrication; and instrumentation.

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Design and Fabrication of Instrumented Composite Tails for the Pathfinder I Model. Hollingsworth, W. H., Jr.; and Adderholdt, B. M., pp. 323-329, X89-10025#.

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National Transonic Facility Model Attitude Systems. Finley, T. D., pp. 371-386, X89-10030#.

Status of Model Deformation Systems. Snow, W. L.; and Gray, D. L., pp. 387-408, X89-10031#.

Panel Discussion Synopsis

Design and Fabrication Costs for Cryogenic Models. pp. 409-414.

502. *Bruce, W. E., Jr.: **Test Experience in the National Transonic Facility.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 1-16.

X89-10006#

During this time of checkout and calibration some aerodynamic research tests also took place in the U.S. National Transonic Facility (NTF). Some of the tests were run in air at ambient temperatures and the remaining tests were at cryogenic temperatures. The NTF submarine test was a very difficult cryogenic test that used a large model, required very exacting alignment of the model with the free-stream flow, and used several channels of hot-film instrumentation. As a result of the calibration of this hot-film instrumentation, the low-speed turbulence level in the NTF was measured. The U.S. Navy has found the results of the NTF submarine test to be very valuable in guiding future submarine design.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

503. *Ray, E. J.: **Test Experience in the 0.3-m TCT.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 17-34.

X89-10007#

This paper covers the evolution and general characteristics of the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT), the cryogenic model challenge, and highlights of the cryogenic model test experience gained in this facility.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

504. *Young, C. P., Jr.: **Overview of Cryogenic Model Technology Activities at the Langley Research Center.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 35-50.

X89-10008#

This paper gives highlights of the technology development activities since the first workshop held at the NASA Langley Research Center May 5–9, 1982. Current activities are described along with planned activities.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

505. *Cockrell, C. E.: **Model System Criteria Update.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 51-63.

X89-10009#

Design criteria were developed at the NASA Langley Research Center which includes special requirements for the design and building of models for cryogenic tunnels. The criteria are presented for the design, analysis, quality assurance, and documentation of wind-tunnel model systems. Some background leading to the current criteria are reviewed briefly and then the key items are discussed.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

506. *Cockrell, C. E.: **Design of Cryogenic Models.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 65-78.

X89-10010#

The design and fabrication of wind-tunnel models for the cryogenic environment of the U.S. National Transonic Facility (NTF) confronts the designer with several problems not previously encountered. Each of the problem areas is discussed with the method(s) offered for their practical solution that have proven effective in actual testing.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

507. *Madsen, A. P.: **NTF Generic Wing-Body Model.** (GDFW–Langley Co-op Program). Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 79-96.

X89-10011#

General Dynamics/Fort Worth Operations in cooperation with NASA Langley Research Center designed and had built a generic wing/body model for test in the U.S. National Transonic Facility (NTF), Calspan 8-Foot Transonic, and NASA Langley Research Center 4-Foot Unitary Plan Wind Tunnels. The model will be tested throughout the subsonic, transonic, and supersonic speed range. The model has an unducted fuselage which accepts either of two wing configurations. The first wing is uncambered, and the second is cambered. Each wing has leading edge flaps and trailing edge elevons and ailerons, incorporating deflected as well as zero angle positions.

*General Dynamics, Corp.; Fort Worth Division, P. O. Box 748, Fort Worth, TX 76101 U.S.A.

508. *Smith, D. A.: **F-111 TACT (FAVOR) Model.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 97-112.

X89-10012#

A contract was awarded to design, build, and calibrate a 1/20 scale wind-tunnel model of the TACT-F-111 for testing in the U.S. National Transonic Facility (NTF). Five tasks were involved which include select design conditions that could duplicate flight-test points within the NTF test envelope; perform preliminary detail design, analysis, and selection of fabrication methods and techniques; make proof of concept tests to validate the design and fabrication approaches; fabricate the model; and perform complete model checkout and proof tests.

*Boeing Co., P. O. Box 3707, Seattle, WA 98124 U.S.A.

509. *Lango, K.: **Design Experience.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 113-138.

X89-10013#

Note: No Abstract available.

*Grumman Aerospace Corp., Bethpage, New York U.S.A.

510. *Bunn, L. D.; and *Cooper, M. J.: **DEI Experience With Design, Analysis, and Fabrication of NTF Models.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 139-159.

X89-10014#

The purpose of any analysis is to demonstrate on paper that the design meets mission and safety requirements. The analyses required for a cryogenic wind-tunnel model are listed. Four lessons were learned from the analyses: extensive analysis is required for all models to be tested in the U.S. National Transonic Facility (NTF); interaction between design, analysis, and fabrication departments is critical to the success of the project; analysis of joints using dissimilar materials can become very complex; and Vascomax C-200 continues to be the material of choice.

*Dynamic Engineering, Inc., Newport News, VA U.S.A.

511. *Abel, L. C.; and *Webster, L. F.: **Development of an On Board Data System for Wind Tunnel Models.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 161-169.

X89-10015#

An onboard electro-optics data system offers significant advantages to wind-tunnel users. The capability to obtain force/movement, pressure, and other data simultaneously, with a single test article and single tunnel entry offers potential advantages to the U.S. National Transonic Facility (NTF) in terms of productivity and offers potential cost savings to NTF users in terms of both hardware and wind-tunnel costs.

*Micro Craft, Inc., Tullahoma, TN U.S.A.

512. *Carlson, A. B.; and *Lassiter, W. S.: **Thermal Analysis of Cryogenic Wind-Tunnel Models.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 171-186.

X89-10016#

The design of wind-tunnel models for testing under cryogenic conditions requires that special attention be given to the potential for thermal-stress problems. However, it is not ordinarily difficult to achieve a design which is free from thermal problems, providing the thermal behavior of the model components is kept in mind during the design process. Several models were tested successfully in the U.S. National Transonic Facility (NTF) under cryogenic temperatures, demonstrating the feasibility of the technology.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

513. *Gray, C. E., Jr.: **Analysis and Test of the FAVOR Model Support System for NTF.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 187-204.

X89-10017

The use of the high-Reynolds-number test capability provided by the U.S. National Transonic Facility (NTF) requires that model systems be designed, analyzed, and tested for operation in a cryogenic environment. The combination of model configurations, high-aerodynamic loads, and strength limitations on materials acceptable for use at cryogenic temperatures makes it necessary to design systems to lower safety margins than normally used in conventional wind tunnels. This will dictate that more rigorous and sophisticated analyses be made along with mathematical model verification and proof testing.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

514. *Griffin, S. A.: **Advanced Support Systems for NTF.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 205-224.

X89-10018#

A recent design study by General Dynamics looked at the feasibility of designing high-performance, fighter-type models for the U.S. National Transonic Facility (NTF), and concluded that models could be designed, but pointed out that certain configurations might well be sting-limited because of the higher loads created by the pressure. This lead to a study in which advanced model support systems for NTF were analyzed with the goal of improving the performance of present-day support systems by 25 percent in both stiffness and strength. A number of configurations were evaluated, including advanced composites, superalloys, Kennametal (tungsten), and combinations of these materials (hybrids).

*General Dynamics, Corp.; Convair Division, P. O. Box 85377, San Diego, CA 92138 U.S.A.

515. *Lawing, P. L.; and *Wigley, D. A.: **A New Design Concept for Instrumented Airfoils.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 225-255.

X89-10019#

This paper describes a research and development program to build wind-tunnel pressure models. The program is centered on the concept of bonding together plates with pressure channels cut into the bond planes.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

516. *Bird, R. K.; and *Wagner, J. A.: **Fatigue Behavior of 18 Ni 200 Grade Maraging Steel for Cryogenic Applications.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 257-272.

X89-10020#

The fatigue behavior of 18 Ni 200 grade maraging steel was evaluated for cryogenic use in the U.S. National Transonic Facility (NTF). This material is currently being used to build cryogenic wind-tunnel models and support hardware such as stings and balances.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

517. *Firth, G. C.: **Fasteners, Fillers, and Adhesives.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 273-282.

X89-10021#

Documentation exists to assist the designer in the use of fasteners, fastener retention systems, and filler systems for cryogenic wind-tunnel models. This documentation is augmented by the experience gained in using the 0.3-m TCT and the U.S. National Transonic Facility (NTF).

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

518. *Gibbens, B. V.: **Casting Applications in Cryogenic Wind-Tunnel Model Design.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 283-289.

X89-10022#

A need was recognized for the development of a casting program at NASA Langley in order to increase cryogenic wind-tunnel model fabrication capability. Previously, many models or model components were cast for wind-tunnel testing, however most of these have tended to be noncritical stressed pieces and were not subjected to low temperatures. This program is intended to study and improve casting techniques and capabilities of materials to be used for cryogenic wind-tunnel models.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

519. *Watkins, V. E., Jr.: **Solder Applications for Cryogenic Wind-Tunnel Models.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 291-296.

X89-10023#

This paper discusses the applications and selection of solders suitable for use in cryogenic wind-tunnel models. Since many combinations of materials are possible, only those identified as good candidates were selected for testing. These selections were based on the alloys presently selected for use as base metals for cryogenic models.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

520. *Stroupe, D. D.; and Barclay, T.: **Cryogenic Models Fabrication Experience.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 297-322.

X89-10024#

Cryogenic model fabrication at NASA Langley Research Center is very successful. Over 25 complex three dimensional cryogenic wind-tunnel models were built for testing in the U.S. National Transonic Facility (NTF). With the increasing number of cryogenic models being built, significant experience was realized in improving machining accuracies, refining hand finishing and surface finish techniques, application of instrumentation methods, use of repair techniques to material undercuts, and wing/fuselage intersection machining by electric discharge machining (EDM). The success of the computerized numerical control (CNC) process is a result of continual upgrading of the interface between sophisticated software and efforts to insure good machining accuracy.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

521. *Hollingsworth, W. H., Jr.; and *Adderholdt, B. M.: **Design and Fabrication of Instrumented Composite Tails for the Pathfinder I Model.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 323-329.

X89-10025#

Note: No abstract available.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

522. *Gloss, B. B.; and *Al-Saadi, J.: **Model Surface Finish Studies – A Progress Report.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 331-338.

X89-10026#

The National Bureau of Standards (NBS), under the sponsorship of NASA, undertook a program to quantify the surface roughness of models which are to be tested in the U.S. National Transonic Facility (NTF) and to develop an optical instrument which would be easy to use and would accurately measure the surface roughness on models. The NBS developed techniques, as well as hardware, that allow the accurate mapping of surfaces having roughness of the order of 4 to 32 microinches RMS and also successfully developed an optical instrument to measure those surface finishes. A research program was undertaken by NASA to use the 0.3-m Transonic Cryogenic Tunnel (TCT) and the services of the NBS to determine allowable surface finishes for wind-tunnel models to be tested at high Reynolds numbers. This test program will involve a number of tunnel entries using the same model with a different surface finish tested on the model for each entry. In addition, an effort will be made to establish the functional relationship between skin friction and surface-finish parameters, such as the RMS roughness height and some measure of the roughness wavelength.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.
**North Carolina State University, Raleigh, NC 27695 U.S.A.

523. *Sandefur, P. G., Jr.; and *Firth, G. C.: **Brazing Studies With Applications to X-29A and F-111 Models.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 339-349.

X89-10027#

Brazing is a joining technique used on both conventional and cryogenic wind-tunnel models. This technique was used on secondary and primary structural joints for conventional models for several decades. The difficulties encountered in brazing materials compatible with low temperatures such as process-related distortions, process-related alteration of mechanical properties, and lack of data, has restricted the use of brazing on the critical structures of cryogenic wind-tunnel models. The models presented design and fabrication challenges which could only be answered by using brazing processes. The processes, problems, experiences, and information gained in applying this technique to the two models are discussed.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

524. *Ferris, A. T.: **Dynamic Load Monitoring of Force Balances.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 351-360.

X89-10028#

For over 25 years the dynamic loads imposed on force balances during wind-tunnel testing were not monitored unless the researchers had reason to believe that the dynamic loads were going to be excessive. The increased emphasis placed on safety by NASA, the larger load and temperature range of the U.S. National Transonic Facility (NTF), and the increased cost of models and facilities that may be damaged by a failure, brought about a need for a system that would provide real-time monitoring of the balance dynamic loads. This paper briefly describes the design and fabrication of the instrumentation for dynamic load monitoring of force balances.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

525. *Jacobs, P. F.: **Instrumentation Loads Interference.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 361-370.

X89-10029#

A series of cryogenic cycles were made in the cryo chamber at the U.S. National Transonic Facility (NTF) to identify the cause of apparent strain shifts in axial force with temperature for the Pathfinder I model and to minimize their effects. The results indicated that the major cause of axial force end point shifts and thermal hysteresis loops was the thickness of the Teflon insulation on the instrumentation wires crossing the balance. By reducing the thickness of the insulation and the total number and size of the wires, apparent strain values were achieved for the model with instrumentation wires which were nearly identical to those for the model without wires. Because of the special design features used, the balance output was very accurate and repeatable over the entire NTF temperature range, even with balance thermal gradients as large as 64 F and transient conditions as large as 3 F/min.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

526. *Finley, T. D.: **National Transonic Facility Model Attitude Systems.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 371-386.

X89-10030#

The measurement of model pitch and roll was accomplished using several techniques. The primary measurement system for both pitch and roll is the inertial package which uses precision accelerometers and electrolytic bubbles. Two 3-axis packages are available that measure pitch and roll and provide for a zero reference both upright and inverted. The accuracy of the angle measurements is approximately 0.02 degs in pitch and 0.03 degs in roll. Pitch measurements were also made using an optical interferometer. The results are not as promising since the absolute aspect of the system does not work well and since a frost problem was discovered when the tunnel goes cryogenic. Pitch measurements were made using an accelerometer on the arc sector and correcting for sting and balance deflections using the normal force and pitching moment from the force balance. A precision roll resolver was installed at the rear of the sting assembly to monitor roll for models that were too small to accommodate a 3-axis inertial package. The error in this system was much larger than expected because of coupling problems in the mechanical assembly.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

527. *Snow, W. L.; and *Gray, D. L.: **Status of Model Deformation Systems.** Presented at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 387-408.

X89-10031#

High aerodynamic loads obtainable within the operating range of the U.S. National Transonic Facility prompted the development of nonintrusive methods to measure model deformation. Two independent approaches based on triangulation are discussed. The Video Model Deformation (VMD) system uses conventional television equipment to view passive targets while the Stereo Electro Optical Tracking System (SEOTS) acquires active target (light emitting diodes) information using image dissector cameras. This paper describes these systems.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

528. Design and Fabrication Costs for Cryogenic Models. Panel Discussion Synopsis at the Second Workshop on Cryogenic Wind Tunnel Models–Design and Fabrication, held at NASA Langley Research Center, Hampton, Va., November 3-5, 1987. In: NASA CP-3010 (X89-10005#), October 1988, pp. 409-414.

Note: No abstract available.

529. *Dor, J.-B.; *Archambaud, J.-P.; and *Breil, J. F.: **Etude des Couches Limites Laterales, Avec et Sans Aspiration, pour le Profil CAST 7 de Corde 150 mm, a la Soufflerie T2.** (Sidewall boundary layer study, with and without suction, for the 150 mm chord CAST-7 airfoil at the T2 wind tunnel). RTOA n° 40/3075 AND (DERAT n° 14/5015 DN) December 1987, 19 pp., 4 refs., includes 80 figs., in French.

N89-22584#

This paper presents tests about sidewall effects realized at the T2 transonic wind tunnel equipped with top and bottom adaptive walls. The model is the 150 mm chord CAST 7 airfoil tested with fixed transition at 0.5° angle of attack. The flow field is studied near the solid sidewall, above the downstream part of the model upper side, and in the wake, at Mach number 0.705 and 0.755: directional boundary layer probing, static-pressure measurements, and wall visualizations. Suction rate ($q_{suction}/q_{test\ section}$) of about 4/1000 is achieved on sidewalls, on the downstream part of the model upper side and around the trailing edge. The velocity distribution on the airfoil, the lift coefficient, and the modifications of the sidewall boundary layers (measurements, visualizations) allowed the suction effect to be analyzed.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

530. *Johnson, C. B.; *Carraway, D. L.; **Stainback, P. C.; and ***Fancher, M. F.: **Hot-Film System for Transition Detection in Cryogenic Wind Tunnels.** In: Research in Natural Laminar Flow and Laminar Flow Control, Pt. 2, December 1987, pp. 358-376.

N90-12522#

The determination of the location of boundary-layer transition is often necessary for the correct interpretation of aerodynamic data in transonic wind tunnels. In the late 1970s, the Douglas Aircraft Company developed a vapor deposition hot-film system for transition detection in cryogenic wind tunnels. Tests of the hot-films in a low-speed tunnel demonstrated the ability to obtain on-line transition data with an enhanced simultaneous hot-film data-acquisition system. This paper describes the equipment design and specifications.

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**Analytical Services and Materials, Inc., 107 Research Drive, Hampton, VA 23666 U.S.A.
***Douglas Aircraft Co., McDonnell Douglas Corp., 3855 Lakewood Blvd., Long Beach, CA 90846 U.S.A.

531. *Dress, D. A.; and *Kilgore, R. A.: **Cryogenic Wind Tunnel Research: A Global Perspective.** In: Cryogenics, vol. 28, January 1988, pp. 10-21, 29 refs.

ISSN 0011-2275 A89-29288

The development of cryogenic wind tunnels is reviewed and 13 cryogenic wind tunnels currently operating in England, France, Germany, Japan, and the U.S. are described. A table illustrating the characteristics of these tunnels is presented, including test gases, test section sizes, speed ranges, stagnation pressure and temperature, and running time. The research conducted using the various wind tunnels is outlined and the operation of each of the tunnels is considered.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

532. *Goodyer, M. J.: **Preliminary Experiments on Surface Flow Visualizations in the Cryogenic Wind Tunnel by Use of Condensing or Freezing Gases.** NASA CR-181634, January 1988, 21 pp., 6 refs.

N88-18602#

Cryogenic wind-tunnel users must have available surface flow-visualization techniques to satisfy a variety of needs. While the ideal from an aerodynamic standpoint would be nonintrusive, until an economical technique is developed there will be occasions when the user will be prepared to resort to an intrusive method. One such method is proposed, followed by preliminary evaluation experiments carried out in environments representative of the cryogenic nitrogen tunnel. The technique uses substances which are gases at normal temperature and pressure but liquid or solid at cryogenic temperatures. These are deposited on the model in localized regions, the patterns of the deposits and their subsequent melting or evaporation revealing details of the surface flow. The gases were chosen because of the likelihood that they will not permanently contaminate the model or tunnel. We identified twenty-four gases as possibly suitable and four of these were tested from which we concluded that surface-flow direction can be shown by the method. Other flow details might also be detectable. The cryogenic wind tunnel used was insulated on the outside and did not show signs of contamination. Author

*ViGYAN, Inc., 30 Research Drive, Hampton, VA 23666-1325 U.S.A.

533. *Taylor, C. R.: **Transonic Flow of Cold Nitrogen, Formulae for Free-Stream Conditions of ETW.** RAE TR-88019, March 1988, 19 pp., 13 refs. DCAF F010260.

formerly X90-71009

Note: Limitation removed. Contact the author for copies if unavailable elsewhere.

Using published data, a study of real-gas effects for one-dimensional flows in ETW is presented. The accuracy of perfect-gas relationships is assessed and where these are found to be significantly in error, empirical correction formulae are given. Also presented are new, compact, and accurate approximations for the compressibility factor, speed of sound, dynamic viscosity, and Reynolds number.

*Royal Aircraft Establishment, Farnborough, Hants GU14 6TD, England

534. *Schmitt-von Schubert, B.: **Gas Cooling by Droplet Evaporation. (Kühlung eines Gases durch Tröpfchen-Verdampfung).** Ingenieur-Archiv, vol. 58, no. 3, March 1988, pp. 205-214, 7 refs., in German.

A88-44583

Note: For an English translation of this paper see citation no. [543] in this bibliography.

The cooling of the parallel flow of a gas by injection of droplets of the same material (as in a cryogenic wind tunnel) is investigated theoretically by means of numerical simulations, with a focus on the equalization processes which take place when the temperature, velocity, and vapor pressure of the droplets (considered as a continuum) differ from those of the gas. The derivation of the balance, material, and interaction equations is explained; the final state of the gas after all droplets have evaporated is characterized; and the flow process is described in detail. Numerical results for nitrogen under various initial pressure and density conditions and for different droplet radii are presented in extensive graphs and discussed.

*DFVLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

535. *Yamaguchi, Y.; *Kuribayashi, N.; and *Kaba, H.: **Characteristics for Ambient Conditions of NDA Cryotunnel Cryogenic Operation.** Paper presented at the 19th Annual Meeting of the JSASS, April 5-6, 1988, pp. 73-74.

Note: For a later paper on this subject see citation no. [580] in this bibliography.

The National Defense Academy (NDA) built a 2-D cryogenic tunnel in 1985 for basic aerodynamic research using the cooling method developed at the NASA Langley Research Center. The tunnel calibration tests and improvement of the cryogenic operation method have been made. The velocity distribution, turbulence level, and boundary-layer thickness of the side wall were measured at several cross sections. The test section for ambient conditions and the original manual control system were modified to one of a limited automatic cryogenic operation to maintain more accurate cryogenic conditions. The calibration and operational tests show that the present tunnel has sufficient capability for a 2-D tunnel, and that the new control system works well. The time for cryogenic operation increased about 1.5 times as long as that of the original system.

*National Defense Academy, 10-20 Hashirimizu 1-Chome, Yokosuka-Shi, Kanagawa-Ken 239, Japan

536. *Kilgore, R. A.; *Dress, D. A.; *Wolf, S. W. D.; and **Britcher, C. P.: **Test Techniques: A Survey Paper on Cryogenic Tunnels, Adaptive Wall Test Sections, and Magnetic Suspension and Balance Systems.** Presented at the Transonic Symposium held at NASA Langley Research Center, Hampton, VA, April 19-21, 1988, In: NASA CP-3020, (N89-20942), vol. 1, pt. 2, pp. 705-715, 30 refs.

N89-20955#

Our ability to get good experimental data in wind tunnels is often compromised by things seemingly beyond our control. Inadequate Reynolds number, wall interference, and support interference are three of the major problems in wind-tunnel testing. Techniques for solving these problems are available. Cryogenic wind tunnels solve the problem of low Reynolds number. Adaptive wall test sections can go a long way toward eliminating wall interference. A magnetic suspension and balance system (MSBS) completely eliminates support interference. We are beginning to realize the potential of these techniques. This survey paper covers cryogenic tunnels, adaptive wall test sections, and MSBS. We give a brief historical overview and describe the present state of development and application in each area. Finally, we attempt to predict future developments and applications of these test techniques.

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**Old Dominion University, Norfolk, VA 23508-0369 U.S.A.

537. *McKinney, L. W.; *Bruce, W. E., Jr.; and *Gloss, B. B.: **National Facility Status.** Presented at the Transonic Symposium held at NASA Langley Research Center, Hampton, Va., April 19-21, 1988. In: NASA CP-3020, vol. 2, (X89-10342), pp. 1-39, 16 refs., includes 38 figs.

X89-10343#

The U.S. National Transonic Facility (NTF) has been operational in a combined checkout and test mode for about 3 years. During this time there have been many challenges associated with movement of mechanical components, operation of instrumentation systems, and drying of insulation in the cryogenic environment. Most of these challenges have been met to date along with completion of a basic flow calibration and aerodynamic tests of a number of configurations. This paper reviews some of the major challenges resulting from the cryogenic environment with regard to hardware systems and data quality. Reynolds number effects on several configurations are also discussed.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

538. *Ng, W. F.; *Gundappa, M.; and **Peterson, J. B., Jr.: **Turbulence Measurements in a Transonic Cryogenic Wind Tunnel.** Presented at the 15th Aerodynamic Testing Conference, May 18-20, 1988, San Diego, Calif., 10 pp., 11 refs. (This paper is not included in the Conference volume. Requests for this paper should be by the AIAA paper number.)

AIAA Paper 88-2026 Request by AIAA Paper Number

Note: Also in AIAA Journal, vol. 28, May 1990, pp. 853-858.

A high-frequency combination probe was used to measure dynamic flow quality in the test section of the NASA Langley 0.3-m Transonic Cryogenic Tunnel. The probe measures stagnation (total) temperature and pressure, static pressure, and flow angles in two orthogonal planes. Simultaneous unsteady temperature and pressure measurements were also made in the settling chamber of the tunnel. The data show that turbulence intensities increase by almost a factor of four as the flow accelerates from the settling chamber to the test section. In the test section, the maximum rms values of the normalized fluctuating Mach number and flow angle are 2.0 percent and 0.5 degree, respectively.

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539. *Wolf, S. W. D.; and **Ray, E. J.: **Highlights of Experience With a Flexible Walled Test Section in the NASA Langley 0.3-Meter Transonic Cryogenic Tunnel.** In: AIAA Aerodynamic Testing Conference, 15th, San Diego, Calif., May 18-20, 1988, Technical Papers (A88-37907), 1988, pp. 321-330, 18 refs.

AIAA Paper 88-2036 A88-37938#

Note: This paper was published later as NASA TM-101491. See citation no. [577] in this bibliography.

This paper describes the unique combination of adaptive wall technology with a continuous-flow cryogenic wind tunnel. This powerful combination allows wind-tunnel users to carry out two-dimensional (2-D) tests at flight Reynolds numbers with wall interferences essentially eliminated. Validation testing was made to support this claim using well-tested symmetrical and cambered airfoils at transonic speeds and high Reynolds numbers. The test section hardware has four solid walls, with the floor and ceiling being flexible. This paper outlines the method of adapting/shaping the floor and ceiling to eliminate top and bottom wall interference at its source. The highlights of our testing experience involve discussion of data comparisons for different size models tested by us and others in several sophisticated 2-D wind tunnels. In addition, we examine the effects of Reynolds number, testing at high lift with associated large flexible wall movements, the uniqueness of the adapted wall shapes, and the effects of sidewall boundary layer control. The 0.3-m TCT is now the most advanced 2-D wind-tunnel facility anywhere.

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540. *Macha, J. M.; *Landrum, D. B.; **Pare, L. A.; and ***Johnson, C. B.: **Heating Requirements and Nonadiabatic Surface Effects for a Model in the NTF Cryogenic Wind Tunnel.** In: AIAA Aerodynamic Testing Conference, 15th, San Diego, Calif., May 18-20, 1988, Technical Papers (A88-37907), 1988, pp. 372-381, 20 refs.

AIAA Paper 88-2044 A88-37944#

A theoretical study has been made of the severity of nonadiabatic surface conditions arising from internal heat sources within a model in a cryogenic wind tunnel. Local surface heating is recognized as having an effect on the development of the boundary layer, which can introduce changes in the flow about the model and affect the wind-tunnel data. The geometry was based on the NTF Pathfinder I wind-tunnel model. A finite element heat-transfer computer code was developed and used to compute the steady state temperature distribution within the body of the model from which the surface temperature distribution was extracted. Particular three-dimensional characteristics of the model were represented with various axisymmetric approximations of the geometry. This analysis identified regions on the surface of the model susceptible to surface heating and the magnitude of the respective surface temperatures. It was found that severe surface heating may occur in particular instances, but could be alleviated with adequate insulating material. The heat flux through the surface of the model was integrated to determine the net heat required to maintain the instrumentation cavity at the prescribed temperature. The influence of the non-adiabatic condition on boundary layer properties and on the validity of the wind-tunnel simulation was also studied.

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NASA Grant NAG1-417

541. *Bruce, W. E., Jr.; *Gloss, B. B.; and *McKinney, L. W.: **Testing and Checkout Experiences in the National Transonic Facility Since Becoming Operational.** Paper presented at the 2nd ETW Cryogenic Technology Review Meeting, held at Cologne, Germany, June 28-30, 1988, 24 pp., 15 refs.

A88-49378#

The U.S. National Transonic Facility, built at NASA Langley to meet the national needs for High-Reynolds-Number Testing, has been operational in a checkout and test mode since the operational readiness review (ORR) in late 1984. During this time, there have been problems centered around the effect of large temperature excursions on the mechanical movement of large components, the reliable performance of instrumentation systems, and an unexpected problem of moisture in the internal insulation. This paper reviews the more significant efforts since the ORR and summarizes the NTF status concerning hardware, instrumentation and process control systems, operating constraints imposed by the cryogenic environment, and data quality and process controls.

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542. *Hancy, J. P.; and *Muylaert, J.: **PETW Testing Results.** Presented at the 2nd ETW Cryogenic Technology Review Meeting held in Cologne, Germany, June 28-30, 1988, 12 pp., 23 figs.

A90-34226#

After a short historical review of the Pilot European Transonic Windtunnel (PETW), a description of the facility is given. The main differences with the present status of ETW are headlined. A review of the early operations of the tunnel precedes a more general presentation of the test results obtained up to now, with some emphasis given to their impact on the final design of ETW. Finally, some indications on the future use of PETW are presented.

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543. *Schmitt-von Schubert, B.: **Model Calculations of Nitrogen Cooling by Droplet Evaporation.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held in Cologne, Germany, June 28-30, 1988, 7 pp., 8 refs. Also in Ingenieur-Archiv., vol. 58, no. 3, 1988, pp. 205-214.

ISSN 0020-1154 In English A90-34227#
In German A88-44583

Note: For the original German form see citation no. [534] in this bibliography.

It is important that liquid nitrogen drops blown into cryogenic wind tunnels to provide cold should evaporate before reaching the test section. In this paper, model calculations on the one-dimensional flow of a mixture of gaseous nitrogen and nitrogen droplets are presented. It is found that if the vapor pressure, temperature, and velocity of the droplets differ from the corresponding values for the gas at some initial station, equalizing processes occur. The influence of the initial values on individual cases in which the droplets are completely evaporated in the final state are discussed.

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544. *Kilgore, R. A.: **Cryogenic Wind Tunnels in Japan.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held at Cologne, Germany, June 28-30, 1988, 24 pp., 8 refs.

A90-34228#

This paper briefly reviews the cryogenic wind-tunnel activities in Japan. The emphasis is on the mechanical, aerodynamic, and operational aspects of the four cryogenic tunnels in Japan. Two new transonic cryogenic tunnels have been proposed to meet the high-Reynolds-number testing needs in Japan. The first would have a 0.6-m × 0.6-m test section and serve as a pilot tunnel for a much larger tunnel. The larger tunnel would have a 3-m × 3-m test section. It would operate at Mach numbers from 0.2 to 1.2 and at pressures up to 9 bars.

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545. *Stainback, P. C.; and *Owen, F. K.: **Hot Wire Anemometry in Transonic Flows and Cryogenic Conditions.** Presented at the 2nd ETW Cryogenic Technology Review Meeting held at Cologne, Germany, June 28-30, 1988, 10 pp., 15 refs.

A90-34229#

The recent development of advanced transonic wind tunnels required to obtain high-quality aerodynamic data has greatly increased the need for making flow-quality measurements in the test section of these facilities. Techniques in hot-wire anemometry have been developed in attempts to properly quantify the levels of disturbances in transonic tunnels. This report will briefly review hot-wire anemometry in transonic flows, present a technique for overcoming some of the problems associated with hot wire measurements in transonic flows, present some data obtained using this technique, note problems associated with other techniques, and point out some of the problems associated with obtaining hot-wire data at transonic speeds and cryogenic conditions.

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546. *Viehweger, G.: **The Kryo-Kanal, Köln, KKK: Description of Tunnel Conversion. Results of Calibration Tests Under Ambient and Cryogenic Conditions.** Paper presented at the 2nd ETW Cryogenic Technology Review Meeting held in Cologne, Germany, June 28-30, 1988, 17 pp., 9 refs., includes 25 figs.

A90-34230#

The modified Kryo-Kanal at Köln (KKK) is described, including the test section, fan and drive system, liquid nitrogen system, exhaust and blow-in system, and internal insulation. Modeling and control of the tunnel is analytically discussed, and the aerodynamic and cryogenic calibration of the tunnel are reviewed. The temperature of the test gas in the modified tunnel can be varied with a range of 300 and 100 K. The maximum Reynolds number achieved at the lower temperature is 8.9×10^6. Even at the lowest tunnel temperature, the deviation of the temperature in the test section never exceeds ±0.5 K.

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547. *Bald, W. B.: **Force Balance Errors Due to Temperature Changes in ETW.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held in Cologne, Germany, June 28-30, 1988, 13 pp., 6 refs.

A90-34231#

Previous work has shown that heated balances are unacceptable for use in ETW. More recent investigations have also shown that using the complete model-balance-sting assembly to predict force changes in balances directly from the changes in stream temperature are also inaccurate. An alternative approach, including a thermal load analysis on the simple RAE gauge link balance, is presented here and compared with measured transient load changes. It is found that attempting to predict the temperature-induced force balance changes in ETW by thermally modeling the complete model-balance-sting assembly itself, rather than measuring changes in stream temperature, will also lead to unacceptable errors. The number of temperature sensors required to monitor thermal transients within the balance itself can be minimized by using finite element modeling of the balance together with an appropriate measured boundary condition.

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548. *Thomason, A.: **Investigation of Model Rigging Limitations on a High Speed Wind Tunnel Model at Cryogenic Temperature.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held in Cologne, Germany, June 28-30, 1988, 7 pp., 4 refs., 8 figs.

A90-34232#

Model rigging experiments were carried out on a 1/20 scale military aircraft model in a cryogenic chamber. A model-rigging technique was developed in which configuration changes could be achieved with the rigger wearing unsophisticated protective clothing and using inexpensive tools and model aids. However, the tests showed that configuration changes would be much easier to accomplish if the cold model is rigged in a dry ambient atmosphere.

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549. *König, H. G.; and *Ewald, B.: **A Measurement Window for a Cryogenic Windtunnel.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held in Cologne, Germany, June 28-30, 1988, 8 pp., 2 refs.

A90-34233#

A medium-sized thermal isolating window for direct viewing into the measurement section of a cryogenic wind tunnel has been constructed. The basic principle of the window involves a two-pane structure with a high-vacuum isolation gap in between. The calculation of the thermal flux through the window and its optical performance, safety, and reliability are discussed. The design of the window is addressed, examining the cold seals, evacuation system, and heating techniques. Test results of the window are summarized which indicate that a window of this type would allow application of highly-sophisticated measurement techniques like schlieren methods, interferometry, LDA, L2F, and optical triangulation which previously had mostly been used at room temperatures and away from wind-tunnel measurement sections.

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550. *Goodyer, M. J.: **Surface Flow Visualization in the Cryogenic Wind Tunnel.** Paper presented at the 2nd ETW Cryogenic Technology Review Meeting held at Cologne, Germany, June 28-30, 1988, 18 pp., 14 refs.

A90-34234#

The prospects are reviewed of a range of possible surface-flow-visualization methods for application to model testing in a large cryogenic wind tunnel. Desirable features are outlined, including the flow details which should be revealed by the various methods. The risks of model and tunnel contamination are discussed as well as the coverage of the model surface to be expected, the advance planning and complexity of model design and tunnel equipment required by the visualization method, and the prospects of generating multiple flow images during one tunnel run. The techniques range from the untried to several on which already there is some experience in the cryogenic environment. Directions for further development are suggested.

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NAS1-17919

551. *Rivet, G.; and *Lequime, M.: **Model Attitude Measurement System.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held in Cologne, Germany, June 28-30, 1988, 11 pp., 5 refs.

A90-34235#

An optical system for accurately measuring the attitude of a model being tested inside a transonic wind tunnel is described. The system sensitivity is presented and a quantitative analysis of the Moiré effect applied to the system's optical reflector is given. The system is particularly attractive for application to angle variation measurements. Its performance in terms of sensitivity and linearity is good and the reflector assembly, being a passive device, is not too sensitive to the environment.

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552. *Owen, F. K.; *Orngard, G. M.; *McDevitt, T. M.; and *Ambur, T. A.: **A Dynamic Optical Model Attitude Measurement System.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held in Cologne, Germany, June 28-30, 1988, 21 pp., 2 refs.

A90-34236#

A major source of transonic wind-tunnel test data uncertainty is due to angle of attack measurement errors caused by unknown sting and balance deflections under load. Since dynamic loads in the ETW will greatly exceed those in conventional wind tunnels, the need to account for these distortions during model testing will be even more acute. The correct determination of angle of attack will require in-situ measurements so that model deflections and tunnel wall movements due to changes in freestream dynamic pressure and temperature can be accounted for. To meet this challenge, a novel, laser-based instrument for the in-situ measurement of wind-tunnel-model angle of attack in the ETW is proposed. The sensor will enable continuous, time-dependent measurements to be made without signal dropout. The instrument will be inexpensive, compact and robust, and will work when intermittent fog is present. Sensitivities of 0.01 deg. will be possible. The purpose of this research is to determine the feasibility of using this instrument for model attitude measurements in the ETW and to establish design and installation criteria consistent with wind-tunnel constraints.

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553. *Ewald, B.; and *Graewe, E.: **Cryogenic Balance Development.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held in Cologne, Germany, June 28-30, 1988, 16 pp.

For airplane research and development in the wind tunnel, the measurement of overall forces on the model with a balance is the most important and most widely used test technique. Thus, the construction of the ETW as well as other cryogenic tunnels will give little benefit if an accurate balance for the temperature region from ambient to cryogenic is not available. According to the present knowledge of the author, there is no final solution achieved up to now so we are slightly concerned about the fact that, apart from our Darmstadt/MBB group, serious development work on cryogenic balances is done at no other place in Europe. Some more competition and cooperation in this field would be helpful for the future of ETW. In the joined programme of the Technical University of Darmstadt, MBB Transport Division, and the Carl Schenck AG, all aspects of the cryogenic balance problem are treated. In this paper, the balance design problem itself will be discussed. The problems of calibration methods and evaluation software will be discussed in separate papers. The cryogenic balance development programme is funded by the German Ministry of Research and Technology; the development of the calibration method was partly funded by the ETW.

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554. *Ewald, B.; and **Balden, T.: **Balance Calibration and Evaluation Software.** Presented at the 2nd Cryogenic Technology Review Meeting held at Cologne, Germany, June 28-30, 1988, 9 pp., 2 refs.

A90-34237#

A new procedure for evaluating the calibration matrix from calibration data and wind-tunnel test loads from balance readings during wind-tunnel tests is presented. A more or less arbitrary calibration matrix is used to simulate a calibration data set. Calibration data from a cryogenic balance is used to prove the reliability of the method. The advantages of the method, when compared to previous ones, are among others (1) the calibration matrix is evaluated as a closed solution of the whole data set, (2) specific load ranges can easily be extracted from the data set to get a matrix especially for these load ranges, and (3) the third-order formulation of the problem makes it possible to simulate symmetric balance character.

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555. *Gross, U.; and **Lück, H.: **Design and Manufacture of a Cryogenic Wind Tunnel Model.** Presented at the 2nd Cryogenic Technology Review Meeting held at Cologne, Germany, June 28-30, 1988, 20 pp., 10 refs., includes 34 figs.

A90-34238#

The design of the TST cryogenic wind-tunnel model is described. The choice of model scale, general model data, simulation of the flight envelope, model and balance loads, tolerances, and surface requirements are briefly presented. The design of the balance adapter, fuselage, wing, vertical tail, horizontal stabilizer, and attachment screws are examined, and a stress analysis of the TST model is summarized. The material of the model is briefly described and the model instrumentation is outlined. Special problems encountered in the manufacture of the model are reviewed, including those pertaining to the steel material, manufacture pretests, surface quality, stepped specimens, wedge specimens, and three-dimensional specimens. The outlook for the project is briefly addressed.

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**Dornier GmbH–Friedrichshafen 1, Postfach 1420, D-7990 Friedrichshafen 1, FRG

556. *Lamiscarre, B.; *Lempereur, Ch.; and **Pasquet, J. C.: **Feasibility Study of RADAC Stereo Optoelectronic Model Deformation Measurement System for ETW.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held in Cologne, Germany, June 28-30, 1988, 6 pp.

A90-34239#

This paper summarizes the feasibility study of the RADAC stereo optoelectronic model deformation measurement system for ETW. The principles of the RADAC system and of its implementation are summarized. User requirements, model-related requirements, environment requirements, and operational requirements are outlined, as are the RADAC optical principle, acquisition and processing chain principle, and models deformation measurements principle.

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**Intespace, B.P. 4356, F-31029 Toulouse Cedex, France

557. *Blanchard, A.; *Dor, J.-B.; *Seraudie, A.; and *Breil, J. F.: **Flow Quality in the T2 Cryogenic Wind-Tunnel – Problems and Solutions.** Presented at the 2nd ETW Cryogenic Technology Review Meeting held in Cologne, Germany, June 28-30, 1988, 22 pp., 37 refs.

A90-34240#

The T2 wind tunnel is transonic, pressurized, cryogenic, driven by induction, fitted with adaptive walls, and internally insulated. The milestones of this tunnel are reviewed, and its steady flow accuracy, flow unsteadiness, and fluid purity are discussed. Examples of problems encountered by the tunnel are briefly addressed.

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558. *Mignosi, A.; *Archambaud, J.-P.; *Prudhomme, S.; *Plazanet, M.; and *Payry, M. J.: **T2 Ability Concerning Model Design and Instrumentation in Short Run Processing.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held in Cologne, Germany, June 28-30, 1988, 14 pp., 17 refs., includes 19 figs.

A90-34241#

The transonic-induction-driven wind tunnel T2 at ONERA has gained considerable experience in cryogenic testing since 1981. In parallel with the wind-tunnel experience, progress has been made in model design and instrumentation. Following an initial period with bulky airfoils cooled near the test section before the run, low thermal-inertia models have been developed. Their 3 mm thin skin allows cooling by the wind-tunnel flow at low speed of less than one minute. Various types of models that show the increase of complexity and development of technology, ranging from two-dimensional massive models to three-dimensional light models, are described. Finally, T2 model instrumentation is examined relative to pressure and temperature measurement, optical fibers, and accelerometers and strain gauges in a cryogenic environment. Some experimental test results are provided.

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559. *Dupriez, F.; *Geoffroy, P.; and *Outtier, G.: **Half Transport Aircraft Cryogenic Model for T2 Wind Tunnel.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held in Cologne, Germany, June 28-30, 1988, 10 pp., 4 refs., includes 5 photos, 15 figs.

A90-34242#

The design, construction, and instrumentation of a model of a transport aircraft for buffeting tests in the cryogenic T2 wind tunnel are examined. The model and its instrumentation are described, and the FEM and aerodynamic pressure-field modeling are discussed. The evaluation of the deflection and of the stresses of the model under buffeting loads of the dynamic behavior of the clamped wing is addressed. The fuselage and wing-attachment design is described.

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560. *Thomason, A.: **A Feasibility Study for a Combat Aircraft Model Sting for the European Transonic Wind Tunnel.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held in Cologne, Germany, June 28-30, 1988, 21 pp., 3 refs., includes 12 figs.

A90-34243#

The conceptual sting design incorporates a flange joint at the downstream end and a cylindrical taper joint at the model end. The material chosen is DTD 5212, a high-strength maraging steel. A structural analysis of the design has been carried out and recommendations are made regarding future low-temperature toughness testing for the sting material. Based on the conceptual design, indicative costs are included for the detail design, structural analysis and manufacture.

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561. *McCabe, D. F.: **Cold Model Handling Facility, "The Glove Box System."** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held in Cologne, Germany, June 28-30, 1988, 6 pp., includes 3 figs.

A90-34244#

The feasibility of a mobile glove box system for the variable temperature control room (VTCR) cold model handling requirement is assessed. The objective is to create a system capable of working in a cryogenic dry atmosphere, allowing rapid access to the model in a pressurized, closed-circuit wind tunnel with safety and minimal potential for damage to the model. The proposed system comprises four deployable glove box cabins for servicing the model and a separate fixed facility to access the sting. A sealing requirement between the glove box rear section and the VTCR wall is discussed, and the glove box cabin is described. Construction materials for use in cryogenic conditions are assessed and operation of the system is outlined with emphasis on safety.

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562. *Dupriez, F.; *Paluch, B.; *Petitniot, J. L.: **Sting Design Feasibility for E.T.W. Cryogenic Civil Transport Aircraft.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held at Cologne, Germany, June 28-30, 1988, 17 pp., 4 refs., includes 24 figs.

A90-34245#

The feasibility of a straight rear sting with a circular cross section to be used in a cryogenic wind tunnel for civil transport aircraft testing is studied. Design limitations are considered from the point of view of maximum stress as related to fatigue limit stresses, as well as minimum aerodynamic interaction between the model and the sting. Specifications and dimensions are discussed along with materials including metallic alloys and composite materials. Different types of joints are considered and thermal stresses induced by rapid changes in temperature are covered. A family of stings with increasing degrees of aerodynamic interaction is proposed.

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563. *Porter, R.: **A Proposed Automatic Calibration Facility for Cryogenic Balances.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held at Cologne, Germany, June 28-30, 1988, 8 pp., 2 refs., includes 7 figs.

A90-34246#

This paper summarizes the results of a feasibility study of balance calibration methods undertaken for SC-ETW as part of the ETW Cryogenic Technology Programme. The proposed automatic calibration machine uses servo-controlled pneumatic load generators to apply any required combinations of load components. Two systems of jacks are used to maintain the attitude of the live end of the balance and to minimize travel of the load generators. A segmented cooler surrounds the balance for calibration at uniform cryogenic temperatures or with temperature gradients.

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564. *Ewald, B.; **Giesecke, P.; ***Graewe, E.; and ***Balden, T.: **Automatic Calibration Machine for Internal Cryogenic Balances.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held at Cologne, Germany, June 28-30, 1988, 19 pp., including 12 figs.

A90-34247#

A feasibility study to develop an automatic calibration rig for cryogenic balances is offered. Apart from automatic operation, the rig must fulfill any requirements that result from the special technology of cryogenic balances and accuracy requirements. Relevant aspects of accuracy, repeatability and signal resolution, and the calibration structure of the rig are described. Controlling and safeguarding of the applied forces, the cryogenic cooling box, and the data acquisition system are also defined. Finally, some general aspects for the positioning and alignment of the internal balance to be calibrated are discussed.

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565. *Lotter, K.; and *Leistner, R.: **Results of Studies on a Manipulator System for Model Handling in the ETW.** Presented at the 2nd ETW Cryogenic Technology Review Meeting held in Cologne, Germany, June 28-30, 1988, 25 pp., includes 10 figs.

A90-34248#

The use of a manipulator is expected to represent the most harmless procedure for wind-tunnel model modifications in the cold, life-hostile nitrogen atmosphere of the European Transonic Windtunnel (ETW). Unnecessary temperature cycles with the associated thermal stresses in both the model and the wind-tunnel structure can thus be avoided. In addition, higher tunnel productivity and a reduction in energy can be achieved. The system of an electric master-slave-manipulator is described, its applicability for model modifications and instrumentation check-out in the "Variable Temperature Check-out Room" (VTCR) is analyzed, and its feasibility is demonstrated. Future application in the ETW test section has also been considered. The study has confirmed the feasibility of a manipulator system for both the VTCR and the tunnel test section. Implementation in the ETW test section is highly recommended.

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566. *Schulze, B.; *Lange, R.; and *Craubner, S.: **An Infrared Camera System for Detection of Boundary Layer Transition in the ETW.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held in Cologne, Germany, June 28-30, 1988, 18 pp., 6 refs.

A90-34249#

Infrared radiometry/thermography is a feasible test technique for surface-flow visualization in the European Transonic Windtunnel (ETW), especially for detection of boundary layer transition contours on model surfaces. This technique applies remote sensing of infrared radiation from thermal surface patterns corresponding to specific surface-flow phenomena; for example, boundary layer transition. To meet increased requirements at cryogenic temperatures compared to ambient conditions, special detection equipment will be needed. A complete infrared radiometer camera system for ETW operating at temperatures between 100 and 300 K is described considering a cooled extrinsic detector, a dynamic optical focus, and a flexible scanning schedule for individual model dimensions.

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567. *Unger, M.: **Results of Temperature Distribution Calculations With PATRAN and P/THERMAL.** Presented at the 2nd ETW Cryogenic Technology Review Meeting held at Cologne, Germany, June 28-30, 1988, 7 pp., includes 11 figs.

A90-34250#

This paper reports a survey of the capabilities of the PATRAN and P/THERMAL computer codes with respect to 3-dimensional temperature calculations. Computations show that these codes are well suited to define the temperature distribution within complex structures such as wind-tunnel models. A connection to the NASTRAN program allows the determination of the stress distribution and the deformation of the structure.

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568. *Scurlock, R. G.; and *Webb, R.: **Development of Cryogenic Instrumentation for ETW Models.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held at Cologne, Germany, June 28-30, 1988, 11 pp., 7 refs.

A70-34251#

This paper describes a prototype eight-channel (four pressure and four temperature) computer-controlled electronic signal conditioning data logging system capable of operating at temperatures between 77.5 K and 300 K with a precision of ±0.05 percent. To achieve ±0.02 percent requires circuit development as well as temperature correction of the digitized output signals using the temperature signals from the integral diode thermometers mounted on the system pressure sensors; the logger computer can be used to carry out the latter operation on each pressure reading. The logger has 16-channel capability in its present form and since it is constructed in modular form, further 16-channel modules can be added.

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569. *Law, R. D.: **Measurement of Temperature Gradients and Assessment of Balance Performance Using the RAE Cryogenic Test Duct.** Presented at the 2nd ETW Cryogenic Technology Review Meeting, held at Cologne, Germany, June 28-30, 1988, 30 pp., 6 refs., 43 figs.

A90-34252#

Temperature gradients affecting the outputs of strain-gaged balances at cryogenic temperatures are studied. For each experiment, an external body of revolution is fitted over the balance to provide shielding from a gas flow. The magnitude and direction of the temperature gradients is evaluated while the flow is cooled from ambient to 90 K. The effect of eliminating convection currents within and around the balance using a polystyrene infill is assessed. It is demonstrated that thermally induced force excursions in the gage linked balance during the thermal transients can be established from the measured temperature data as well as by direct force measurements. An axial force calibration carried out at ambient and cryogenic temperatures is analyzed to assess sensitivity changes, along with pitch and normal force interactively to assess any changes in the magnitude of these interactions at low temperatures.

*Royal Aircraft Establishment, Bedford, Beds MK41 6AE, England

570. *Heinzerling, W.: **The Case for Breathable Atmosphere in the European Transonic Wind-Tunnel ETW.** Presented at the 2nd ETW Cryogenic Technology Review Meeting held in Cologne, Germany, June 28-30, 1988, 13 pp., 15 refs.

The effect of ambient temperature operation of the ETW with a breathable atmosphere on flexibility and productivity of the facility during commissioning, calibration, inspection, and maintenance phases of the tunnel as well as during industrial test programmes is demonstrated. A preliminary concept for a breathable atmosphere system is presented. Technical problems put forward during the previous design phase as for example, stratification of oxygen and nitrogen in the circuit, accumulation of oxygen inside the internal insulation, health hazard for personnel due to dry atmosphere, contamination of tunnel gas by CO_2, and water vapor from personnel are discussed and corresponding solutions are indicated. The necessary software and hardware provisions for the tunnel are discussed briefly. It is concluded that breathable atmosphere operation at ambient temperature as an additional mode of tunnel operation is feasible and cost-effective. The productivity and the flexibility of the tunnel during commissioning, calibration, inspection, maintenance and industrial testing will be significantly improved.

*Messerschmitt-Bölkow-Blohm GmbH–München, Postfach 801109, D-8000 München 80, FRG

571. *Green, J. E.: **Optical Measurements of Model Attitude: Comment on Effect of Refraction by Density Gradients in Tunnel Flow.** Presented at the 2nd ETW Cryogenic Technology Review Meeting held at Cologne, Germany, June 28-30, 1988, 10 pp., includes 7 figs.

Comments are given on the papers by Rivet and Owen (citation nos. [551 and 552]) which describe alternative techniques for measuring model attitude optically, the accuracy of the methods used is the subject of this paper.

*Aircraft Research Association Limited, Manton Lane, Bedford MK41 7PF, England

572. *Van Sciver, S. W.; and *Wiesend, J. G., II.: **Design and Operation of a Horizontal Liquid Helium Flow Facility.** Presented at the 12th International Cryogenic Engineering Conference and Exhibition, Southampton, England, July 12-15, 1988, 6 pp., 5 refs., CONF-880736--6; DE 89 013482.

N89-26867#

The University of Wisconsin horizontal liquid helium flow facility (LHFF) consists of a five meter long 20 cm ID horizontal dewar connected to two end boxes. Several heat exchanger inserts have been built to allow variable temperature operation with $1.6\ K \le T \le 4.2\ K$. A centrifugal pump is installed at one end of the facility permitting experiments in forced flow liquid helium up to 100 gm/s. The horizontal design allows experimentation on long straight test sections which may be used either to study fundamental properties of heat and mass transfer in helium or prototype cryogenic components under realistic conditions. This paper gives a detailed description of the design and operating experience of the LHFF.

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Contract DE-AC02-86ER-40306

573. *Borisov, S. Yu.; *Kulesh, V. P.; and *Naumov, A. M.: **Study of the Quality of the Flow in an Ejector Cryogenic Wind Tunnel.** (Issledovaniye Kachestva Potoka v Ezhektornov Kriogennoy Aerodinamicheskoy Trube). Paper presented at the International Seminar "Problems of Simulation in Wind Tunnels" held at the Institute of Theoretical and Applied Mechanics of the U.S.S.R., Novosibirsk, U.S.S.R., July 25-29, 1988, pp. 117-124. English translation is NASA-TT-20463, X89-10302.

Various methods in this report are described along with the results of experimental studies on determining the quality of the flow in a cryogenic, supersonic ejector wind tunnel. Tests were carried out to study the following: the process for the formation and disappearance of fog and ice crystals in the reverse channel, the equality of the temperature distribution in the forechamber and the Mach number in the working part, the features of the flow in the working part of the continuous cooling of the flow, flow purity, and the action of extraneous particles on the model.

*Central Aero-Hydrodynamic Institute (TsAGI), U.S.S.R.
Contract (for translation) NASW-4307

574. *Kozlov, V. V.; *Omelaev, A. I.; and *Ramazanov, M. P.: **Issledovaniya Struktury Potoka i Voprosov Modelirovaniya v Dozvukovoy Aerodinamicheskoy Trube pri Kriogennykh Temperaturakh.** (Flow Structure Investigation and Modeling in Subsonic Wind Tunnel at Cryogenic Temperatures). Paper presented at the International Seminar "Problems of Simulation in Wind Tunnels" held at the Institute of Theoretical and Applied Mechanics of the U.S.S.R., Novosibirsk, U.S.S.R., July 25-29, 1988, pp. 136-145, in Russian. English translation is NASA-TT-20385, X88-10422, October 1988, 16 pp.

To solve the complex scientific-technical problems of developing cryogenic wind tunnels, the U.S.S.R. Academy of Sciences Institute of Theoretical and Applied Mechanics has modernized the existing low velocity wind tunnel with a working area of 0.2 × 0.2 m, so that it may operate at the cryogenic temperatures of the working gas. The parameters of this tunnel are given along with several results of measuring the flow structure at normal and cryogenic temperatures.

*Central Aero-Hydrodynamic Institute (TsAGI), U.S.S.R.

575. *Wolf, S. W. D.: **Application of a Flexible Wall Testing Technique to the NASA Langley 0.3-m Transonic Cryogenic Tunnel.** Paper presented at the ICAS 16th Congress, Jerusalem, Israel, August 28 - September 2, 1988. In: Proceedings, vol. 2, (A89-13501), Washington, D.C., AIAA, Inc., 1988, pp. 1181-1191, 24 refs.

ICAS-88-3.8.2 A89-13820#

Wind-tunnel wall interference can be minimized by means of a flexible wall technique, whose application to the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) is presently discussed. The adaptable test section of the TCT has four solid walls, of which only the floor and ceiling are adaptable; these are computer-controlled to minimize wall contour-definition times, and can operate at cryogenic temperatures and high pressures despite large wall deflections. This paper presents both two- and three-dimensional test data illustrative of the experience gained with the TCT system over the course of two and a half years of operation.

*ViGYAN, Inc., 30 Research Drive, Hampton, VA 23666-1325 U.S.A.

576. *Kilgore, R. A.; and *Lawing, P. L.: **Cryogenic Wind Tunnels for High Reynolds Number Testing.** Paper presented at the ICAS 16th Congress at Jerusalem, Israel, August 28 - September 2, 1988. In: Proceedings, vol. 2, (A89-13501), Washington, D.C., AIAA, Inc., 1988, pp. 1199-1209, 36 refs.

ICAS-88-3.8.4 A89-13622#

This paper begins with a brief review of cryogenic wind tunnels and their use for high-Reynolds-number testing. Emphasis is on operational experience and recent aerodynamic testing in the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT). Specific areas covered in this paper include development of test techniques and aerodynamic testing in cryogenic tunnels. This paper also gives details of research experience in developing model construction techniques, including airfoils as thin as 5 percent. The use of advanced testing techniques to increase the value of cryogenic tunnels to the research community is recommended. These include adaptive wall test sections using solid but flexible top and bottom walls and magnetic suspension and balance systems.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

577. *Wolf, S. W. D.; and **Ray, E. J.: **Highlights of Experience with a Flexible Walled Test Section in the Langley 0.3-Meter Transonic Cryogenic Tunnel.** NASA TM-101491, September 1988, 11 pp., 18 refs.

N89-10060#\
N89-10061#

Note: For an earlier presentation see citation no. [539] in this bibliography.

The unique combination of adaptive wall technology with a continuous-flow cryogenic wind tunnel is described. This powerful combination allows wind-tunnel users to carry out two-dimensional (2-D) tests at flight Reynolds numbers with wall interferences essentially eliminated. We highlight validation testing to support this claim using well tested symmetrical and cambered airfoils at transonic speeds and high Reynolds numbers. We briefly describe the test section hardware which has four solid walls, with the floor and ceiling being flexible. We outline the method of adapting/shaping the floor and ceiling to eliminate top and bottom wall interference at its source. The highlights of our testing experience involve discussion of data comparisons for different size models tested by us and others in several sophisticated 2-D wind tunnels. In addition, we examine the effects of Reynolds number, testing uniqueness of the adapted wall shapes and the effects of sidewall boundary layer control. Our 2 years of operational experience with the adaptive wall test section hardware and its associated control system has taught us important lessons about design and operating procedures. We conclude that the 0.3-m TCT is now the most advanced 2-D research facility anywhere.

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578. *Wigley, D. A.: **Technology for Pressure-Instrumented Thin Airfoil Models. Final Report.** NASA CR-4173, September 1988, 44 pp.

N88-28933#

A novel method of airfoil model construction has been developed during this program. This "Laminated Sheet" technique uses 0.8 mm thick sheets of A286 containing a network of pre-formed channels which are vacuum brazed together to form the airfoil. A 6.25 percent model of the X29A canard, which has a 5 percent thick section, has been built using this technique. The model contained a total of 96 pressure orifices, 56 in three chordwise rows on the upper surface and 37 in three similar rows on the lower surface. The model was tested in the NASA Langley 0.3-m Transonic Cryogenic Tunnel. Unique aerodynamic data was obtained over the full range of temperature and pressure. Part of the data was at transonic Mach numbers and flight Reynolds number. A large two dimensional model of the NACA 65a-105 airfoil section was also built. Scale-up presented some problems, but the airfoil was testable.

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Contract NAS1-18066

579. *Lawing, P. L.; **Wigley, D. A.; and ***Glaab, L. J.: **Construction of Airfoil Pressure Models Using the Multiple Plate Method.** Presented at SAE AEROTECH 88, In: Proceedings of the 7th Aerospace Behavioral Technology Conference at Anaheim, Calif., October 3-6, 1988, 9 pp., 8 refs.

TL710.A485 1988

This paper describes a research and development program to build wind-tunnel pressure models. The program is centered on the concept of bonding together plates with pressure channels cut into the bond planes. Photographic "masking" combined with chemical milling is a reliable and cost effective method of providing pressure channels suitable for high-density pressure instrumentation with minimum demand on parent model material. Small diameter high-quality pressure orifices (that is, round holes with smooth edges) are economically produced when pre-drilled holes are cut at the model surface by the wire-cut process. With care in the choice of materials and technique, vacuum brazing can be used to produce strong bonds without blocking pressure channels and with no bonding voids between channels. Using multiple plates, a wing with a thickness of 5 percent of chord and having 96 orifices has been constructed and tested in a transonic cryogenic wind tunnel.

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***Joint Institute for Advancement of Flight Sciences, George Washington University, Hampton, VA 23665-5225 U.S.A.

580. *Yamaguchi, Y.; *Kaba, H.; *Kuribayashi, N.; and **Yoshida, S.: **Preliminary Test Results of NDA Cryogenic Wind Tunnel and its System.** Presented at the SAE Aerospace Technology Conference and Exposition, Anaheim, Calif., October 3-6, 1988, 16 pp., 31 refs.

SAE Paper 881449 A89-28219#

This paper presents the major design specifications of the National Defense Academy (NDA) cryogenic wind tunnel, together with the results on the preliminary calibration tests of the tunnel. The NDA tunnel, designed for two-dimensional airfoil testing, was constructed using the SUS 304 stainless steel as the material for the pressure shell. The results of the operational and the calibration tests at ambient and cryogenic temperatures demonstrated that the NDA cryogenic tunnel has sufficient potential as a tunnel for performing low-temperature transonic flow experiments.

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**Japan Defense Agency, 7-45 Akasaka 9, Minato-ku, Tokyo 107, Japan

581. *Kanda, H.; *Sawada, H.; and *Suenaga, H.: **The Calibration of a Model Position and Attitude Sensor With the One-Dimensional Array CCD Image Sensors.** Presented at the JSASS Aircraft Symposium, October 21, 1988, 4 pp., 4 refs., in Japanese.

A new sensor to measure 5 components of model position and attitude at a 10 cm distance from the model was developed. This sensor consists of three 1D array CCD image sensors arranged in an H-shape. A series of calibration tests of the sensor were conducted. It was found that the sensor has an accuracy of 0.3% FS in the X and Z direction while it has much more error to the transverse movement of a model. This error is due to that an image of a model (or a mark on the model) becomes out of focus in these directions. It was also found that cross-coupling effects are large in the outputs in the transverse directions.

*National Aerospace Laboratory, 7-44-1 Jindaiji-machi Chofu-shi, Tokyo 182, Japan

582. *Baljeu, J. F.: **Development of a Multi-Component Internal Strain-Gauge Balance for Model Tests in a Cryogenic Wind Tunnel.** NLR-TR-88157 U, October 30, 1988, 96 pp., 9 refs.

N90-12628#
NLR order number 563.607

A three-component internal strain-gauge balance for use in a cryogenic wind tunnel has been developed by NLR. With the balance, model tests were made in the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT). The results are discussed with a view to the development of strain-gauge balances for the ETW.

*National Aerospace Laboratory, 1006 BM Amsterdam, The Netherlands

583. *Young, C. P., Jr.; and *Gloss, B. B., Compilers: **Second Workshop on Cryogenic Wind-Tunnel Models - Design and Fabrication.** Held at NASA Langley Research Center, November 3-5, 1987. NASA CP-3010, (X89-10006), October 1988, 409 pp.

X89-10005#

Note: For individual papers from this conference, see citation nos. [502 through 528] in this bibliography.

The first workshop on cryogenic wind-tunnel models was held on May 5-9, 1982 at NASA Langley Research Center (LaRC). Since 1982 a large number of models have been tested at full-scale Reynolds number in a cryogenic environment. Since many cryogenic models had been designed, built, and tested in the U.S. NTF and the LaRC 0.3-meter Transonic Cryogenic Tunnel, and significant advances in cryogenic model technology had been made, it was appropriate that a second workshop be held. Also, the experience gained in designing and building cryogenic wind-tunnel models over the past five years exists within a large number of organizations. There was a strong need to bring this experience together and to share information among all interested parties. As a result, the workshop included representatives from government, the airframe industry, and model design and fabrication companies. Cryogenic wind-tunnel model topics addressed include design, analysis, test development, fabrication, and instrumentation.

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584. *Bouis, X.: **Studies of the European Transonic Wind Tunnel. Final Rept.** ONERA-RSF-12/0694-GY. Rept. no. ETN-89-95019, December 1988, 16 pp., 13 refs., in French.

N90-13278#

The stages of planning and development of the European Transonic Wind Tunnel are described. Progress in resolving budgetary and technical problems is outlined. Changes in administration and personnel involved in the project are listed. Contracts and costs involved in the project are outlined. An operating scenario is presented. An hierarchical list of the different sectors and managers involved in the project is provided.

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585. *Schmitt-von Schubert, B.: **Gas Cooling by Droplet Evaporation.** In: Ingenieur-Archiv, vol. 58, no. 3, 1988, pp. 205-214, 7 refs., in German.

ISSN 0020-1154 A88-44583#

Note: For a related paper see citation no. [543] in this bibliography.

The cooling of the parallel flow of a gas by injection of droplets of the same material (as in a cryogenic wind tunnel) is investigated theoretically by means of numerical simulations, with a focus on the equalization processes which take place when the temperature, velocity, and vapor pressure of the droplets (considered as a continuum) differ from those of the gas. The derivation of the balance, material, and interaction equations is explained; the final state of the gas after all droplets have evaporated is characterized; and the flow process is described in detail. Numerical results for nitrogen under various initial pressure and density conditions and for different droplet radii are presented in extensive graphs and discussed.

*DLR–Göttingen, Bunsenstrasse 10, D-3400 Göttingen, FRG

586. *Gloss, B. B.; and *Bruce, R. A.: **A Solution to Water Vapor in the National Transonic Facility.** Presented at the 27th AIAA Aerospace Sciences Meeting, Reno, Nev., January 9-12, 1989, 9 pp., 5 refs.

AIAA Paper 89-0152 A89-25135#

As cryogenic wind tunnels are used, problems associated with the low-temperature environment are being discovered and solved. Recently, water vapor contamination was discovered in the U.S. National Transonic Facility. The source was found to be the internal insulation which is a closed-cell polyisocyanurate foam. After a study of the absorptivity characteristics of the NTF thermal insulation, the most practical solution to the problem was shown to be the maintaining of a dry environment in the tunnel circuit at all times. Using a high aspect ratio transport model, it was shown that the moisture contamination effects on the supercritical wing pressure distributions were within the accuracy of setting test conditions and as such were considered negligible for this model.

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587. *Balakrishna, S.; *Kilgore, W. A.; and *Murthy, A. V.: **Performance of the Active Sidewall Boundary-Layer Removal System for the Langley 0.3-Meter Transonic Cryogenic Tunnel.** NASA CR-181793, February 1989, 24 pp., 7 refs.

N89-21004#

A performance of an active sidewall boundary-layer removal system for the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT) was evaluated in 1988. This system uses a compressor and two throttling digital valves to control the boundary-layer mass flow removal from the tunnel. The compressor operates near the maximum pressure ratio for all conditions. The system uses a surge prevention and flow recirculation scheme. A microprocessor based controller is used to provide the necessary mass flow and compressor pressure ratio control. Initial tests on the system indicated problems in realizing smooth mass flow control while running the compressor at high-speed and high-pressure ratios. An alternative method has been conceived to realize boundary-layer mass flow control which avoids the recirculation of the compressor mass flow and operation near the compressor surge point. This scheme is based on varying the speed of the compressor for a sufficient pressure ratio to provide needed mass flow removal. The system has a mass flow removal capability of about 10% of test section flow at M=0.3 and 4% at M=0.8. The system performance has been evaluated in the form of the compressor map and compressor-tunnel interface characteristic covering most of the 0.3-m TCT operational envelope. A simple analytical model which describes the compressor-tunnel interface flow mechanics has been proposed and validated.

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Contract NAS1-17919

588. *Balakrishna, S.; and *Kilgore, W. A.: **Microcomputer Based Controller for the Langley 0.3-M Transonic Cryogenic Tunnel.** NASA CR-181808, March 1989, 148 pp., 15 refs.

N89-22616#

Flow control of the NASA Langley 0.3-meter Transonic Cryogenic Tunnel (TCT) is a multivariable nonlinear control problem. In this work, globally stable control laws have been generated to hold tunnel conditions in the presence of geometrical disturbances in the test section and precisely control the tunnel states for small and large set point changes. The control laws are mechanized as four inner control loops for tunnel pressure, temperature, fan speed, liquid nitrogen supply pressure, and two outer loops for Mach number and Reynolds number. These integrated control laws have been mechanized on a 16-bit microcomputer working on DOS. This document details the model of the 0.3-m TCT, control laws, microcomputer realization, and its performance. The tunnel closed loop responses to small and large set point changes are presented. The controller incorporates safe thermal management of the tunnel cooldown based on thermal restrictions. The controller is shown to provide control of temperature to ±0.2 K, pressure to ±0.07 psia, and Mach number to ±0.002 of a given set point during aerodynamic data acquisition in the presence of intrusive geometrical changes like flexwall movement, angle-of-attack changes, and drag rake traverse. The controller also provides a new feature of automatic Reynolds number control. The controller provides a safe, reliable, and economical control of the 0.3-m TCT.

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Contract NAS1-17919

589. *Paluch, B.: **Feasibility Study of a Sting Designed for the European Cryogenic Wind Tunnel.** In: ONERA 1988 Activities, April 1989, pp. 263-265, in English.

Note: For papers on this subject see citation nos. [560 and 562] in this bibliography.

This research was aimed at designing and dimensioning a civil aircraft support sting satisfying the following criteria: (1) reasonable aerodynamic interaction between the sting and model; and (2) maximum coverage of the flight envelope as regards the Mach number and stagnation pressure (P_i) authorized in this wind tunnel. The worst case conditions were taken with reference to a civil transport aircraft of the A340 type for a Mach number of 0.95 and a stagnation pressure of up to 4.5 bars. Two coefficients characteristic of the fatigue limit and divergence limit respectively were used during the dimensioning phase. For the material, a martensitic stainless steel, with a relatively high-yield modulus and strength at low temperatures (E = 220 GPa, σ_R = 1,600 MPa) was selected. This choice was also conditioned by the relative availability of supply and ease of machining of this material.

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590. *Goodyer, M. J.: **Introduction to Cryogenic Wind Tunnels.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 1, 11 pp., 11 refs.

N90-15940#

The cryogenic wind tunnel was conceived as a way of increasing Reynolds number in a wind tunnel while avoiding an increase in its size. This it does very effectively and with some other surprisingly beneficial effects. Important among these is a reduction of tunnel drive power and the ability for the first time in a wind-tunnel test to identify the separate effects of Reynolds number, Mach number, and dynamic pressure. This lecture forms a brief introduction at the fundamental level highlighting some of the characteristics of cryogenic wind tunnels and their flows.

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591. *Ray, E. J.: **The NASA Langley 0.3-Meter Transonic Cryogenic Tunnel.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 2, 21 pp., 39 refs.

N90-15941#

The NASA Langley 0.3-meter Transonic Cryogenic Tunnel (0.3-m TCT) was placed in operation at the NASA Langley Research Center in 1973 as the world's first cryogenic pressure tunnel. The 0.3-m TCT can operate from ambient to cryogenic temperatures at absolute pressures ranging from about 1 to 6 atm. Three major test section concepts have been developed and refined in this unique wind tunnel. The 0.3-m TCT has been a leader in the evolution of cryogenic pressure wind-tunnel test techniques, instrumentation, control strategy, and model technology. This paper presents an overview of the evolution of the 0.3-m TCT and 15 years of operational experience. This historical background concentrates on the proof-of-concept studies and the technical challenges of bringing on line the first cryogenic pressure wind tunnel. The three test sections used with the 0.3-m TCT are described. Highlights of operational experience and test results determined from these first exploratory tests are presented. Operating costs and effective test techniques for the 0.3-m TCT are discussed. Finally, plans for the 0.3-m TCT are presented.

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592. *Bruce, W. E., Jr., and *Gloss, B. B.: **The U.S. National Transonic Facility, NTF.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 3, 27 pp., 17 refs.

N90-15942#

The construction of the U.S. National Transonic Facility (NTF) was completed in September 1982 and the start-up and checkout of tunnel systems were made over the next two years. In August 1984, the Operational Readiness Review (ORR) was held and the NTF was declared operational for final checkout of cryogenic instrumentation and control systems and for the aerodynamic calibration and testing to commence. Also, the model access system for the cryogenic mode of operation would be placed into operation along with tunnel testing. Since the ORR, a host of operating problems resulting from the cryogenic environment have been identified and solved. These range from making mechanical and electrical systems functional to eliminating temperature induced model vibration to coping with the outgassing of moisture from the internal thermal insulation. Additionally, a series of aerodynamic tests have demonstrated data quality and provided research data on several configurations. This paper will review some of the more significant efforts since the ORR and summarize the NTF status concerning hardware, instrumentation and process controls systems, operating constraints imposed by the cryogenic environment, and data quality.

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593. *Viehweger, G.: **The Kryo-Kanal Köln, (KKK): Description of the Tunnel Conversion. Thermal Insulation, Instrumentation, Operational Experience, Test Results, and Operating Costs.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 4, 17 pp., 10 refs.

N90-15943#

The construction of the Kryo-Kanal-Köln was completed in May 1985. After checkout of all systems the aerodynamic and cryogenic calibration was started one year later and completed in the third quarter of 1988. During this time, operating problems in the circuit and in the subsystems resulting from the cryogenic mode of operation were identified and solved. Some basic tests were made to understand the physics of the desorption of moisture from the internal insulation. The aerodynamic tests demonstrated the flow quality in the test section. This paper gives a review on the experimental experience and the test results gathered during the calibration phase.

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594. *Kronen, R.: **Automatic Control of KKK Requirements, Sensors, Actuators, and Control Performance Results.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 5, 11 pp., 11 refs.

N90-15944#

A new control system was necessary after the modification of the low-speed wind tunnel at the DLR Research Center at Köln to a cryogenic wind tunnel. Some mathematical models were developed for layout of the control system and for studying the tunnel behavior. The models and the controller were tested by computer simulations. Furthermore, the control system was tested with the real tunnel for the run-up, testing, and run-down phases of operation.

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595. *Bouis, X.: **The European Transonic Windtunnel (ETW).** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 6, 16 pp., 11 refs.

N90-15945#

The construction phase of the European Transonic Windtunnel (ETW) started recently at Köln, Germany. Ambitious goals in aerodynamic quality and cost-effectiveness are reflected in the design philosophy. This paper gives the main features of the ETW.
*European Transonic Windtunnel GmbH–Köln 90, Linder Höhe, D-5000 Köln 90, FRG

596. *Archambaud, J.-P.: **The Cryogenic Induction Tunnel T2 at Toulouse.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 7, 12 pp., 14 refs.

N90-15946#

This paper presents the activity of the ONERA-CERT in the aerodynamic cryogenic experimental branch. The paper first describes the T2 induction wind tunnel, which has been operating at cryogenic conditions since 1981, and indicates the flow characteristics. The paper then describes the hollow model concept and shows how it is cooled during the run and underlines the importance of the wall temperature measurements. The paper describes the presence of ice particles in the flow, which cause early transition on the model. It then describes an efficient solution which gives fairly good results on a laminar profile at high Reynolds number. Finally the paper shows cryogenic test results on a three-dimensional model.

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597. *Hefer, G.: **The Cryogenic Ludwieg Tube Tunnel at Göttingen.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 8, 7 pp., 4 refs.

N90-15947#

A cryogenic Ludwieg-tube wind tunnel for transonic operation has been built at the Research Center of the DLR in Göttingen. The tunnel, having an effective run time of 1 second, a test section of 0.4×0.35 m^2, and a maximum stagnation pressure of 10 bars, is to be operated with nitrogen at temperatures between ambient and 120 K, achieving a Reynolds number of 70 million based on a model chord of 0.15 m. This lecture gives a brief review of the Ludwieg tube concept, the main design features of the tunnel, the status of the project, and the first calibration results.

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598. *Kilgore, R. A.: **Other Cryogenic Wind Tunnel Projects.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 9, 12 pp., 27 refs.

N90-15948#

The first cryogenic tunnel was built in 1972. Since then, many cryogenic wind-tunnel projects have been started at aeronautical research centers around the world. This lecture describes some of the more significant of these projects not covered by other lecturers at this Special Course. Described in this lecture are cryogenic wind-tunnel projects in five countries: **China** (Chinese Aeronautical Research and Development Center); **England** (College of Aeronautics at Cranfield, and Royal Aerospace Establishment - Bedford); **Japan** (National Aerospace Laboratory, University of Tsukuba, and National Defense Academy); **United States** (Douglas Aircraft Co., University of Illinois at Urbana-Champaign, and NASA Langley); and **U.S.S.R.** (Central Aero-Hydrodynamics Institute [TsAGI], Institute of Theoretical and Applied Mechanics [ITAM], and Physical-Mechanical Institute at Kharkov [PMI-K]).

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

599. *Wigley, D. A.: **Cryogenic Engineering and Materials.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 10, 18 pp., 19 refs.

N90-15949#

This paper summarizes the effects of cryogenic temperatures on the mechanical and physical properties of materials. Heat capacity and thermal conductivity are considered in the context of conservation of liquid nitrogen, thermal stability of the gas stream, and the response time for changes in operating temperature. Particular attention is given to the effects of differential expansion and failure due to thermal fatigue. Factors affecting safety are discussed, including hazards created due to the inadvertent production of liquid oxygen and the physiological effects of exposure to liquid and gaseous nitrogen, such as cold burns and asphyxiation. The preference for using f.c.c. metals at low temperatures is explained in terms of their superior toughness and the limitations on the use of ferritic steels is also considered. Nonmetallic materials are discussed, mainly in the context of their LOX compatibility and their use in the form of foams and fibres as insulants, seals, and fibre-reinforced composites.

*Cryogenic, Marine and Materials Consultants Ltd., 17 Bassett Wood Drive, Bassett, Southampton, SO2 3PT, England

600. *Bazin, M.: **Instrumentation for Cryogenic Wind Tunnels.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989). ONERA TP-1989-81, Paper no. 11, 31 pp., 21 refs., (includes 32 detailed drawings.)

N90-15950#
A89-48763#

This paper discusses the types of instrumentation needed to ensure measurement quality in cryogenic wind tunnels equal to that obtained in large industrial wind tunnels. Wind-tunnel balances, balance calibration rigs, in situ instrumentation, and optical methods are addressed. Instruments which are used for flow visualization around models, thermovision, model attitude measurements, and deformation measurements are examined.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

601. *Mignosi, A.: **Fundamental Considerations in Testing in Cryogenic Wind Tunnels.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 12, 12 pp., 24 refs.

N90-15951#

The cryogenic technology for wind-tunnel testing is strongly connected with the aerodynamic requirements. This paper addresses a number of aerodynamic problems mainly related to cryogenic testing. The first part describes the various factors involved to achieve the best similarity possible between an aircraft in flight and the model in the wind tunnel. The second part covers the analysis of these factors: effect of a nonadiabatic wall, boundary layer transition, two-dimensional and three-dimensional tests, and effects of the Reynolds number. In this paper, I attempt to alternate theoretical considerations with practical examples to illustrate the importance of "experimental/theoretical" correlations.

*ONERA/CERT, 2, av. Edouard-Belin, B.P. 4025, F-31055 Toulouse Cedex, France

602. *Lawing, P. L.: **Test Techniques for Cryogenic Wind Tunnels.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 13, 12 pp., 29 refs.

N90-15952#

This paper brings together some of the testing techniques developed for transonic cryogenic tunnels. It emphasizes techniques which required special development or were unique because of the opportunities offered by cryogenic operation. The first part of the paper discusses measuring the static aerodynamic coefficients normally used to determine component efficiency. The first topic is testing of two dimensional airfoils at transonic speeds and flight values of Reynolds number. Three dimensional tests of complete configurations and sidewall mounted wings are also described. Since flight Reynolds numbers are of interest, free transition must be allowed. A discussion is given of wind tunnel and model construction effects on transition location. The second part of this paper deals with time dependent phenomena, fluid mechanics, and measurement techniques. The time dependent, or unsteady, aerodynamic test techniques described include testing for flutter, buffet, and oscillating airfoil characteristics. Topics related to nonintrusive laser techniques include optical access, seeding, forward scatter lasers, two-spot lasers, and laser holography. Methods of detecting transition and separation are reported and a new type of skin-friction balance is described.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

603. *Goodyer, M. J.: **Flow Visualization in the Cryogenic Wind Tunnel.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 14, 11 pp., 17 refs.

N90-15953#

This paper describes a range of flow-visualization methods for possible use when testing models in a large cryogenic wind tunnel. Desirable features are outlined, including the flow details which should be revealed by the various methods. The risks of model and tunnel contamination are discussed. Also discussed is the coverage of the model surface to be expected, the advance planning and complexity of model design and tunnel equipment required by the visualization method, and the prospects of generating multiple flow images during one tunnel run. The methods outlined are at an early stage of development but in all cases there is some cryogenic experience to support their consideration for use in the cryogenic environment. None of the methods are well established for use at the highest-Reynolds-number conditions attainable in the cryogenic pressure tunnel.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

604. *Wigley, D. A.: **Materials and Techniques for Model Construction.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 15, 19 pp., 31 refs.

N90-15954#

The problems facing the designer of models for cryogenic wind tunnel models are discussed with particular reference to the difficulties in obtaining appropriate data on the mechanical and physical properties of candidate materials and their fabrication technologies. The relationship between strength and toughness of alloys is discussed in the context of maximizing both and avoiding the problem of dimensional and microstructural instability. All major classes of materials used in model construction are considered in some detail and selected numerical data is given for the most relevant materials in the Appendix. The stepped-specimen programme to study stress-induced dimensional changes in alloys is discussed in detail together with interpretation of the initial results. The methods used to bond model components are considered with particular reference to the selection of filler alloys and temperature cycles to avoid microstructural degradation and loss of mechanical properties.

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605. *Wigley, D. A.: **Some Recent Developments in Materials & Techniques for Model Fabrication.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 16, 10 pp.

N90-15955#

This paper considers the following three topics: the laminated thin sheet technology used in fabrication of a model of the X29A canard that enabled a uniquely high number of pressure orifices to be placed in a thin airfoil; the different configurations of samples used for studies on materials and fabrication techniques for model construction, and; the long term objective of creating a handbook, database or expert system to bring together the information already available and indicate those areas where further work is needed.

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606. *Lawing, P. L.: **Models for Cryogenic Wind Tunnels.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 17, 14 pp., 13 refs.

N90-15956#

Model requirements, types of models, model construction methods, and research in new ways to build models are the topics of this paper. The NASA Langley 0.3-m Transonic Cryogenic Tunnel (0.3-m TCT) has been in operation for 16 years and many 2-D airfoil pressure models have been tested. In addition, there have been airfoil models dedicated to transition detection techniques and other specialized research. There have also been a number of small 3-D models tested. This paper describes the chronological development in model building techniques which led to the construction of many successful models. The difficulty of building good models is illustrated by describing several unsuccessful model building attempts. The U.S. National Transonic Facility (NTF), a newer and much larger cryogenic tunnel, has been used to test a variety of models including a submarine, transport and fighter aircraft, and the Space Shuttle Orbiter. Also described is a new method of building pressure models which has been developed. The method is based on the concept of bonding together plates with pressure channels etched into the bond planes, which provides high-density pressure instrumentation with minimum demand on parent model material. With care in the choice of materials and technique, we can use vacuum brazing to produce strong bonds without blocking pressure channels and with no bonding voids between channels. Using multiple plates, we have built a 5 percent thick wing with 96 orifices and tested it in the 0.3-m TCT. Samples of test data are presented and future applications of the technology are suggested.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

607. *Balakrishna, S.: **Automatic Control of Cryogenic Wind Tunnels.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 18, 15 pp., 10 refs.

N90-15957#

Inadequate Reynolds number similarity in testing of scaled models affects the quality of aerodynamic data from wind tunnels. This is due to scale effects including boundary-layer shockwave interaction which is likely to be severe at transonic speeds. The idea of operation of wind tunnels using test gas cooled to cryogenic temperatures has yielded a quantum jump in our ability to realize full scale Reynolds number flow similarity in small transonic tunnels. In such tunnels, the basic flow-control problem consists of obtaining and maintaining the desired test section flow parameters. Mach number, Reynolds number, and dynamic pressure are the three flow parameters that are usually required to be kept constant during the period of model aerodynamic data acquisition. This paper describes the series of activities involved in modeling, control law development, mechanization of the control laws on a microcomputer, and determining the performance of a globally stable automatic control system for the 0.3-m Transonic Cryogenic Tunnel (TCT). The paper describes the lumped multi-variable nonlinear dynamic model of the cryogenic tunnel, the generation of a set of linear control laws for small perturbation, and the nonlinear control strategy used for large set point changes including tunnel trajectory control. The paper also gives the details of mechanization of the control laws on a 16 bit microcomputer system, the software features, operator interface, the display, and safety. The controller is shown to provide globally stable and reliable temperature control to ±0.2 K, pressure control to ±0.07 psi, and Mach number control to ±0.002 of the set point values. This performance is obtained both during large set point commands, such as experienced during a tunnel cooldown, and during aerodynamic data acquisition with intrusive activity which results in geometrical changes in the test section. These activities include angle of attack changes, drag rake movements, wall adaptation, and sidewall boundary-layer removal. The feasibility of the use of an automatic Reynolds number control mode with fixed Mach number control is demonstrated.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

608. *Williams, M. S.: **Experience with Strain Gage Balances for Cryogenic Wind Tunnels.** Presented (by Walter E. Bruce) at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989. In: AGARD-R-774, (N90-15939#, November 1989), Paper no. 19, 14 pp., 3 refs.

N90-15958#

The U.S. National Transonic Facility (NTF) is a cryogenic wind tunnel built to meet the United States' need for high-Reynolds-number testing. The facility was declared operational in August 1984 and since that time, numerous models have been tested in the NTF using unheated strain-gage balances to measure aerodynamic forces. The difficulty in accurately measuring forces and moments of models in conventional wind tunnels becomes more challenging at cryogenic conditions. The Force and Strain Instrumentation Section of the Instrument Research Division at NASA Langley Research Center designed and fabricated the balances to measure forces at cryogenic temperatures without thermally controlling the balance temperature. Presented in this paper are balance results from a recent cryogenic test program in the NTF. The data indicated the accuracy with which aerodynamic forces are determined using current instrumentation and test methods as well as identified areas for future research.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

609. *Ferris, A. T.: **Cryogenic Balances for the U.S. NTF – Status Report.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 20, 10 pp., 8 refs.

N90-15959#

Force balances have been used to obtain aerodynamic data in the U.S. National Transonic Facility (NTF) cryogenic wind tunnel since it became operational in 1983. These balances were designed, built, gaged, and calibrated to operate over the temperature range of -320 °F to 140 °F without thermal control. This paper reviews some of the materials and procedures developed to obtain a balance that would work well in this environment. It also reports on the degree of success in using these balances, specifies some of the problem areas that need additional work, and describes some of the progress in solving these problems.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

610. *Ray, E. J.: **Safety and Cryogenic Wind Tunnels.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 21, 28 pp., 11 refs.

N90-15960#

The NASA Langley 0.3-meter Transonic Cryogenic Tunnel (0.3-m TCT) was placed in operation at the NASA Langley Research Center in 1973 as the world's first cryogenic pressure tunnel. The 0.3-m TCT can operate from ambient to cryogenic temperatures over an absolute pressure range from about 1 to 6 atm. Three major test section concepts have been developed and refined in this unique facility. The 0.3-m TCT has been a leader in the development of various cryogenic-pressure wind-tunnel experimental techniques, instrumentation, control, model technology, and safety standards. This paper concentrates on the safety experience gained by the author who has been the safety head at the 0.3-m TCT during the facility's 15 years of operation. During this period of advanced research, new operating techniques, training policies, and procedures had to be established. The paper deals with the "Dos" and "Don'ts" of cryogenic wind-tunnel testing. Hazards and safety requirements which are unique to testing in cryogenic wind tunnels are discussed. Highlights of experience and "lessons learned" with the 0.3-m TCT are reviewed.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

611. *Christophe, J.: **Productivity and Cryogenic Wind Tunnels.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#, November 1989), Paper no. 22, 14 pp., 27 refs. Also: ONERA TP no. 1989-80, 1989.

N90-15961#
A89-48762#

The characteristics of five wind tunnels, the ONERA-CERT T2, the NASA Langley 0.3-m TCT, the DLR KKK, the U.S. NTF, and the future ETW are addressed. The characteristic values of the nitrogen consumption are examined, and the thermal balance is discussed. Guidelines for the designers of future wind tunnels are suggested and unconventional wind-tunnel schemes are examined. After a brief review of the situation of existing cryogenic wind tunnels, the thermal balance of five wind tunnels is discussed. This discussion of the thermal balance is then generalized to suggest guidelines for the designers of the future cryogenic wind tunnels. Finally, with the same concern, unconventional schemes are examined.

*ONERA, B.P. 72, F-92322 Châtillon Cedex, France

612. *Lawing, P. L.: **Energy Management and Recovery.** Presented at the AGARD-FDP/VKI Special Course, *Advances in Cryogenic Wind Tunnel Technology*, held at the von Karman Institute for Fluid Dynamics, Rhode-Saint-Genèse, Belgium, June 5-9, 1989, AGARD-R-774, (N90-15939#), Paper no. 23, 9 pp., 10 refs.

N90-15962#

Energy management is treated by first looking at the energy requirements for a cryogenic tunnel. The requirement is defined as a function of Mach number, Reynolds number, temperature, and tunnel size. A simple program and correlation is described which allow calculation of the energy required. Energy usage is also addressed in terms of tunnel control and research operation. The potential of a new wet expander is outlined in terms of cost saved by reliquefying a portion of the exhaust. The expander is described as a potentially more efficient way of recovering a fraction of the cold nitrogen gas normally exhausted to the atmosphere from a cryogenic tunnel. The role of tunnel insulation systems is looked at in terms of requirements, safety, cost, maintenance, and efficiency. A detailed description of two external insulation systems is given. One is a rigid foam with a fiber glass and epoxy shell. The other is composed of glass fiber mats with a flexible outer vapor barrier; this system is nitrogen purged. The two systems are compared with the purged system being judged superior.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

613. *Balakrishna, S.; and *Kilgore, W. A.: **The NASA Langley Research Center 0.3-m Transonic Cryogenic Tunnel T-P/Re-M Controller Manual.** NASA CR-181868, July 1989, 40 pp., 3 refs.

N89-26869#

A new microcomputer based controller for the 0.3-m Transonic Cryogenic Tunnel (TCT) has been commissioned in 1988 and has reliably operated for more than a year. The tunnel stagnation pressure, gas stagnation temperature, tunnel wall structural temperature, and flow Mach number are precisely controlled by the new controller in a stable manner. This report describes the tunnel control hardware, software, and the flow chart to assist in calibration of the sensors, actuators, and the controller real time functions. The software installation details are also presented. The report serves as the maintenance and trouble shooting manual for the 0.3-m TCT controller.

*ViGYAN, Inc., 30 Research Drive, Hampton, VA 23666-1325 U.S.A.
Contract NAS1-17919

614. *Asai, K.: **Hot-Jet Simulation in Cryogenic Wind Tunnels.** NASA RP-1220, July 1989, 46 pp., 21 refs.

N89-23448#

Simple theoretical calculations have been made to evaluate hot-jet simulation capabilities in cryogenic wind-tunnel testing. The similarity parameters, isentropic flow properties, and normal shock relations were calculated for a variety of jet simulation techniques. The results were compared with those estimated for a full-scale flight condition. It has been shown that cryogenic wind-tunnel testing provides an opportunity for the most accurate hot-jet simulation. By using compressed nitrogen gas at ambient or moderately elevated temperatures as a jet gas, almost all the relevant similarity parameters, including the jet temperature, velocity ratios, and the Reynolds numbers, could be set to full-scale flight values. The only exception was the ratio of specific heats for jet flow. In an attempt to match the ratio of specific heats for the turbojet flow, gases other than pure nitrogen were considered. It was found that a nitrogen and methane mixture at moderately elevated temperatures behaved like the real combustion gas. With this mixture used as a jet gas, complete simulation of the full-scale turbojet exhaust became possible in cryogenic wind tunnels.

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(NASA Langley Research Center, Hampton, VA)

615. *Mitchell, M.; and *Sealey, B. S.: **Thermal Enclosures for Electronically Scanned Pressure Modules Operating in Cryogenic Environments.** NASA TM-101635, August 1989, 16 pp., 3 refs.

N89-27151#

Specific guidelines to design, construct, and test ESP thermal enclosures for applications at cryogenic temperatures are given. The enclosures maintain the ESP modules at a constant temperature (10 C ± 1 C) to minimize thermal zero and sensitivity shifts, to minimize the frequency of expensive on-line calibrations, and to avoid adverse effects on tunnel and model boundary layers. The enclosures are constructed of a rigid closed-cell foam and are capable of withstanding the stagnation pressures to 932kPa (135 psia) without reduction in thermal insulation properties. This construction procedure has been used to construct several thermal packages which have been successfully used in the U.S. National Transonic Facility.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

616. *Schimanski, D.: **Status of the Development Programme for Instrumentation and Test Techniques of the European Transonic Windtunnel - ETW.** Presented at the International Congress on Instrumentation in Aerospace Simulation Facilities (13th), held at DLR Research Center in Göttingen, Germany, September 18-21, 1989. In: ICIASF '89 Record, (A90-28251), pp. 450-459, 1989, 17 refs.

A90-28292

Feasibility studies concerned with instrumentation and test techniques for the ETW are summarized. During the functional design phase (1986-88), instruments and techniques for application in cryogenic wind tunnels were studied. The studies were focused on items which might influence the design of the test section area (flow-field observation, surface-flow visualization, model attitude, and deformation measurement) and which might improve the test capability of the facility (engine simulation, model handling, and balance calibration). It is noted that precise knowledge of model loads, model position, model configuration, and the surrounding flow conditions are essential for testing Reynolds-number effects. Standard equipment (strain-gage balances, light sources, cameras, windows, etc.) is being studied. The ETW operating conditions (cryogenic temperatures and limited access) require special arrangements with innovative design and creative ideas even for these standard items.

*European Transonic Windtunnel GmbH–Köln 90, Linder Höhe, D-5000 Köln 90, FRG

617. *Yamaguchi, Y.; *Kaba, H.; *Kuribayashi, N.; *Nakauchi, Y.; and **Yoshida, S.: **Instrumentation and Operation of NDA Cryogenic Wind Tunnel.** Presented at the International Congress on Instrumentation in Aerospace Simulation Facilities (13th), held at DLR Research Center in Göttingen, Germany, September 18-21, 1989. In: ICIASF, '89 Record, A90-28251, pp. 460-469, 24 refs.

A90-28293

The Japanese NDA 0.06 × 0.30-m cryogenic wind tunnel was constructed in 1985 for testing transonic airfoils and other basic research. Design choices included stainless steel SUS 304 as the material for the pressure shell, a centrifugal compressor, and external insulation. Although no information was available on problems using SUS 304 at cryogenic temperature, and although the thermal conductivity of SUS 304 is worse than that of Al alloys, only eight thermocouples were installed to monitor the thermal condition of the shell. The original temperature control (manual control of liquid nitrogen injection into the tunnel circuit) was found to be inadequate because the settling time of the total temperature took about 15 minutes when the rotational speed of the compressor was changed. The total-pressure control systems were modified to simple automatic PID controls; as a result, the control of both pressure and temperature were greatly improved (the settling time of temperature was greatly reduced).

*National Defense Academy, 10-20 Hashirimizu 1-Chome, Yokosuka-Shi, Kanagawa-Ken 239, Japan
**Defense Agency, 3rd Institute of Research and Development, Tokyo, Japan

618. *Ewald, B.; **Giesecke, P.; **Polanski, L.; and **Preusser, T.: **Fully Automatic Calibration Machine for Internal 6-Component Wind Tunnel Balance Including Cryogenic Balances.** Presented at the International Congress on Instrumentation in Aerospace Simulation Facilities (13th), held at DLR Research Center in Göttingen, Germany, September 18-21, 1989. In: ICIASF '89 Record, (N90-28251), pp. 470-476, 1989.

A90-28294

An automatic calibration machine for calibrating internal wind-tunnel balances is described. The automation is mainly achieved by using a specially designed force measuring device, similar to an external wind-tunnel balance. The loading is performed by means of six force generators according to the six aerodynamic components of the balance. Consideration is given to the relevant aspects of accuracy, repeatability, and signal resolution; the mechanical design of the calibration rig; the controlling and safeguarding of the applied forces; and some general aspects of the positioning and alignment of the internal balance to be calibrated.

*Technische Hochschule Darmstadt, Karolinenplatz 5, D-6100 Darmstadt, FRG
**Carl Schenck AG, Darmstadt, FRG

619. *Asai, K.: **The Cryogenic Wind Tunnel as a Testing Tool for Airframe/Propulsion Systems.** Presented at the International Sessions in the JSASS (Japan Society for Aeronautical and Space Sciences) 27th Aircraft Symposium in Japan, October 18-19, 1989, 4 pp., 6 refs., in English.

Paper #2F11 A90-40400#

A new approach to the simulation problems of hot-jet exhausts is presented. This method uses the advantages of cryogenic temperatures in wind-tunnel testing. Simple theoretical analyses show that hot-jet exhausts can be simulated in a cryogenic environment by using a gas at ambient or moderately elevated temperatures. Also, it is shown that in cryogenic wind tunnels, all the similarity parameters including the jet-temperature-related parameters and the Reynolds numbers can be matched to the full-scale flight values. The potential advantages of the cryogenic approach are discussed with emphasis on its applications to the testing of airframe and propulsion systems.

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620. *Lawing, P. L.: **Aerodynamic Testing in Cryogenic Nitrogen Gas – A Precursor to Testing in Superfluid Helium.** Presented at the *University of Oregon 7th Conference on Low Temperature Physics*, Eugene, Oregon, October 23-25, 1989, 13 pp., 29 refs.

A90-21933#

Testing techniques for transonic cryogenic tunnels using nitrogen as the test fluid are presented. The measurement of static aerodynamic coefficients used to determine component efficiency is discussed, focusing on tests of two-dimensional airfoils at transonic speeds. Also, three-dimensional tests of complete configurations and sidewall-mounted wings are examined. Consideration is given to time-dependent phenomena, fluid mechanics, nonintrusive laser techniques, the detection of transition and separation, and testing for flutter, buffet, and oscillating airfoil characteristics.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

621. *Kilgore, R. A.: **Cryogenic Wind Tunnels.** Presented at the *University of Oregon 7th Conference on Low Temperature Physics*, Eugene, Oregon, October 23-25, 1989, 9 pp., 30 refs.

A90-41726#

This paper opens with a brief review of cryogenic wind tunnels and their use for high-Reynolds-number testing. Emphasis is on operational and aerodynamic testing experience in the NASA Langley 0.3-m Transonic Cryogenic Tunnel (TCT). Since we built the 0.3-m TCT in 1973, it has logged over 8000 hours of running at cryogenic temperatures. We use the 0.3-m TCT for aerodynamic testing and to develop test techniques for cryogenic tunnels. Areas briefly covered in this paper include development of test techniques and aerodynamic testing in cryogenic tunnels. Based on our experience, we recommend using advanced testing techniques to increase the value of cryogenic tunnels to the research community. These include **adaptive wall test sections**, using solid but flexible top and bottom walls, and **magnetic suspension and balance systems.**

622. *Advisory Group for Aerospace Research and Development (AGARD), Paris, France: **Advances in Cryogenic Wind Tunnel Technology.** Lectures given at the AGARD-FDP/VKI Special Course held at the von Karman Institute, Rhode-Saint-Genèse, Belgium on June 5-9, 1989. AGARD-R-774, November 1989, 382 pp.

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Note: Individual papers are placed under dates of presentation (June 5-9, 1989). See citation nos. [589 through 611] in this bibliography.

The purpose of this Special Course was to address, as specifically as possible, current concerns with trying to build and use cryogenic wind tunnels. It was designed for engineers and managers wishing to obtain in concentrated form the most up-to-date information on cryogenic wind tunnels. This course covered both the theory and practice of cryogenic wind-tunnel design, operation, and use. Since 1980, the AGARD Fluid Dynamics Panel and the von Karman Institute for Fluid Dynamics have sponsored three series of lectures on cryogenic wind tunnels. The lectures of this Special Course are, in many ways, updates of the lectures given in 1980 and 1985. These lectures reflect the progress made in building and using cryogenic tunnels in recent years. The course provided a brief review of the development and early use of cryogenic tunnels and then covered all aspects of the design and operation of cryogenic tunnels. Areas covered include the following: cryogenic engineering and safety, properties of materials at cryogenic temperatures, tunnel design requirements, model design and construction, automatic tunnel control, data acquisition, data accuracy, flow visualization, productivity, and costs of models and operation. The status of cryogenic wind-tunnel projects in AGARD countries and in the rest of the world was also presented. The bound volume of lecture notes also includes a transcription of a question and answer session held at the end of the Special Course.

*AGARD (Advisory Group for Aerospace R&D), NATO, 7 Rue Ancelle, 92200 Neuilly sur Seine, France

623. *Iskra, A. L.; *Borisov, S. Yu.; *Philatov, A. P.; and *Sukhobokov, A. D.: **Cryogenic Induction Wind Tunnel T-04 TsAGI.** December 25, 1989, 10 pp., 4 figs., 8 refs.

Note: Request the NASA Langley Technical Library for this report.

This paper gives the background, description, and principle of operation of the first Soviet transonic, cryogenic wind tunnel with $0.2 \times 0.2\ m^2$ test section and regenerative cooling system. It is shown that the tunnel can operate for more than 1.5 hour at the flow temperature of less than 150 K without precooling the test gas and with satisfactory stability of temperature, pressure, and Mach numbers. The paper also gives the basic test performances of the wind tunnel over its normal and cryogenic operating ranges.

*Central Aero-Hydrodynamic Institute (TsAGI), U.S.S.R.

624. *Borisov, S. Yu.; *Iskra, A. L.; and *Naumov, A. M.: **Characteristics of Temperature and Pressure Generation and Retention in Flow Inside Cryogenic Wind Tunnel T-04.** (Osobennosti ustanovieniia i podderzhaniia temperatury i davieniia v potoke kriogennoi aerodinamicheskoi truby T-04.) In: TsAGI, *Uchenye Zapiski*, vol. 20, no. 6, 1989, pp. 105-109, 7 refs., in Russian.

ISSN 0321-3439 A90-46576

Results of experiments concerned with the measurement of flow pressure and temperature in a cryogenic wind tunnel with an ejector drive are presented for different operating modes. It is shown that the cold regeneration system makes it possible to maintain a uniform flow temperature field at temperatures above 100 K. A comparative analysis of flow characteristics is carried out for wind operation at normal and cryogenic temperatures.

*Central Aero-Hydrodynamic Institute (TsAGI), U.S.S.R.

625. *Popernack, T. G.; and *Adcock, J. B.: **Cryogenic Temperature Effects on Sting-Balance Deflections in the National Transonic Facility.** NASA TM-4157, January 1990, 9 pp., 4 refs.

N90-14244#

A study was made in the U.S. National Transonic Facility (NTF) at NASA Langley Research Center to document the change in sting-balance deflections from ambient to cryogenic temperatures. Space limitations in some NTF models do not allow the use of onboard angle-of-attack instrumentation. To obtain angle-of-attack data, predetermined sting-balance bending data must be combined with arc-sector angle measurements. Presently, obtaining pretest sting-balance data requires several cryogenic cycles and cold loadings over a period of several days. A method of reducing the required calibration time is to obtain only ambient-temperature sting-balance bending data and to correct for changes in material properties at cryogenic temperatures. To validate this method, two typical NTF sting-balance combinations were tested. The test results show excellent agreement with the predicted values and the repeatability of the data was 0.01°.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

626. *Yamaguchi, Y.; **Yoshida, S.; and *Kaba, H.: **Characteristics of a Cryogenic Wind Tunnel at National Defense Academy. (Part I) The Operation With Manual Controls. Technical Note.** In: Journal of the Japan Society for Aeronautical and Space Sciences, vol. 38, no. 432, January 1990, pp. 49-55, 17 refs., in Japanese.

ISSN 0021-4663

Note: For Part 2, see citation no. [635] in this bibliography.

A 2-dimensional, small high-speed cryogenic wind tunnel was constructed at the National Defense Academy (N.D.A.) in 1985, using the stainless steels of SUS 304 and SCS 13 as materials of the pressure shell. The features of the cryogenic tunnel and its operation procedures are described. The initial operational tests were intensively performed to refine the general operation method to the optimum for the present tunnel with the original manual control systems. Those tests showed that the original control systems were fairly acceptable, but had to be modified to automatic controls for more precise control of the tunnel flow conditions at cryogenic temperature range and to expand the operational envelope.

*National Defense Academy, 10-20 Hashirimizu 1-Chome, Yokosuka-Shi, Kanagawa-Ken 239, Japan
**Japan Defense Agency, 7-45 Akasaka 9, Minato-ku, Tokyo 107, Japan

627. *Donnelly, R. J.; *Smith, M.; and *Swanson, C.: **Superfluid Wind Tunnels.** In: Physics World, February 1990, pp. 39-41, 2 refs.

ISSN UK0953-8585

A liquid-helium tunnel is described which has the potential of making drastic improvements in the testing of ship and aircraft design. Substantial economies of cost in both construction and operation are possible by using liquid helium as the working fluid.

*University of Oregon, Eugene, OR 97403-1274 U.S.A.

628. *Gregory, P. B.; and *Holland, A. D.: **Thermal/Structural Analysis of the Shaft-Disk Region of a Fan Drive System.** NASA TM-101687, March 1990, 29 pp.

N90-22807#

In January 1989, a mishap occurred in the U.S. National Transonic Facility (NTF) wind tunnel at NASA Langley. It is believed that the failure of an insulation retainer holding foam insulation around the exterior of the fan-drive shaft resulted in the subsequent damage to other components in the tunnel. The effect was determined of removing the external thermal insulation on the shaft would have on the stresses on the shaft, disk and bolts holding the two together. To accomplish this, a detailed thermal/structural finite element analysis of the shaft-disk interface was performed. The maximum stresses on the three components were determined for several configurations and conditions with and without the external thermal insulation. These results were then compared to the original analyses to access the effect of removing the external thermal insulation on the proposed future operation of the shaft/disk structures of the fan-drive system. Although the stresses were higher without the external insulation, the stresses did meet all stress criteria. In addition, all stresses were within the infinite-life regime of the Modified Goodman diagram. Therefore, it was determined that the structural integrity of the shaft-disk region is not compromised if the external insulation is removed.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

629. *Ji, G.: **Application of Cryogenic Wind Tunnel With Liquid Nitrogen and Selection of its Temperature Level.** Presented at the 13th International Cryogenic Engineering Conference held in Beijing, People's Republic of China, April 24-27, 1990. In: Cryogenics, Supplement, vol. 30, September 1990, pp. 183-186, 6 refs.

ISSN 0011-2275 A91-12724

This paper gives an account of the essential features and advantages of cryogenic wind tunnels, which allow the testing of models at full scale Reynolds numbers as well as the appropriate Mach numbers. Attention is given to the design and results of a cryogenic wind tunnel operational characterization experiment involving the effects of nitrogen vapor condensation, which degrades the degree of analogous behavior between the cryogenic fluid used and atmospheric air. The experimental results obtained establish that the lower limit of cryogenic fluid temperatures must be the homogeneous condensation temperature of nitrogen.

*Xian Ziaotong University, People's Republic of China

630. *Ng, W. F.; *Gundappa, M.; *Griffith, D. O.; and *Peterson, J. B., Jr.: **Turbulence Measurements and Noise Generation in a Transonic Cryogenic Wind Tunnel.** Presented at the 15th Aerodynamic Testing Conference, San Diego, Calif., (but is not contained in the conference volume). In: AIAA Journal, vol. 28, May 1990, pp. 853-858, 11 refs.

AIAA Paper 88-2026 A90-32463#
ISSN 0001-1452

A high-frequency combination probe was used to measure dynamic flow quality in the test section of the NASA Langley 0.3-m Transonic Cryogenic Tunnel. The probe measures fluctuating stagnation (total) temperature and pressure, static pressure, and flow angles in two orthogonal planes. Simultaneous measurements of unsteady total temperature and pressure were also made in the settling chamber of the tunnel. The data show that the stagnation temperature fluctuations remain constant and the stagnation pressure fluctuations increase by a factor of two, as the flow accelerates from the settling chamber to the test section. In the test section, the maximum rms value of the normalized fluctuating velocity is 0.7 percent. Correlation coefficients failed to show vorticity, entropy, or sound as the dominant mode of turbulence in the tunnel.

*Virginia Polytechnic Institute and State University, Blacksburg, VA 24061 U.S.A.

631. *Ewald, B.; *Giesecke, P.; **Polanski, L.; and ***Graewe, E.: **Automatic Calibration Machine for Cryogenic and Conventional Internal Strain Gage Balances.** Presented at the 16th AIAA Aerodynamic Ground Testing Conference, held at Seattle, Wash., June 18-20, 1990, 10 pp., 7 refs.

AIAA Paper 90-1396 A90-37939#

A fully automatic calibration machine designed to calibrate internal strain-gage balances for conventional tunnels as well as special balances for cryogenic tunnels is described. The general principle of the selected design is presented with emphasis on a system of force generators and an algorithm for processing calibration data mixed with interferences. This algorithm extracts a third-order calibration matrix as a closest least-square error solution from the complete calibration data set. The mechanical design of the machine; including its basic frame, external balance, and loading system, is addressed. A load generation system, external balance technology, and computer control and data system are outlined.

*Technische Hochschule Darmstadt, Karolinenplatz 5, D-6100 Darmstadt, FRG
**Carl Schenck AG, Darmstadt, FRG
***Deutsche Airbus GmbH, Bremen, FRG

632. *Young, C. P., Jr.; *Popernack, T. G.; and *Gloss, B. B.: **National Transonic Facility Model and Model Support Vibration Problems.** Presented at the 16th AIAA Aerodynamic Ground Testing Conference, held at Seattle, Wash., June 18-20, 1990, 10 pp., 8 refs.

AIAA Paper 90-1416 A90-37953#

Vibrations of models and a model-support system were encountered during testing in the U.S. National Transonic Facility (NTF). Model-support system yaw plane vibrations have resulted in model-strain-gage balance-design load limits being reached. These high levels of vibrations resulted in limited aerodynamic testing for several wind-tunnel models. The yaw vibration problem was the subject of an intensive experimental and analytical study which identified the primary source of the yaw excitation and resulted in attenuation of the yaw oscillations to acceptable levels. This paper presents the principal results of analyses and experimental study of the yaw plane vibration problems. Also, an overview of plans for development and installation of a permanent model system dynamic and aeroelastic response measurement and monitoring system for the NTF is presented.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

633. *Murthy, A. V.; and *Ray, E. J.: **Sidewall Boundary-Layer Removal and Wall-Adaptation Studies.** Journal of Aircraft, vol. 27, no. 6, June 1990, pp. 495-500, 13 refs.

AIAA Paper 89-0148 A80-40680#

This paper describes the NASA Langley Research Center 0.3-m Transonic Cryogenic Tunnel sidewall boundary-layer removal system and its integrated operation with the adaptive wall adjustment. Empty test-section measurements show that the sidewall boundary-layer displacement thickness at the model station is reduced from about 1.0 to 0.6% of the test section width when the maximum boundary-layer removal conditions are applied. Tests with a supercritical airfoil model show that the iterative top and bottom wall adaptation process performs satisfactorily with sidewall boundary-layer removal. The top and bottom walls move together to correct for the freestream Mach number changes associated with the boundary-layer removal. The airfoil test showed that the boundary-layer removal does not significantly influence the midspan measurements for thin sidewall boundary layers ($2\delta^*/b<0.01$). With successful operation of iterative wall adaptation and sidewall boundary-layer removal, under cryogenic-pressure conditions, the 0.3-m Transonic Cryogenic Tunnel provides the potential for airfoil testing at flight-equivalent Reynolds numbers and low-wall interference.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

634. *Gartenberg, E.; **Johnson, W. G., Jr.; **Johnson, C. B.; **Carraway, D. L.; and **Wright, R. E.: **Transition Detection Studies in the Cryogenic Environment.** Presented at the AIAA 8th Applied Aerodynamics Conference, Portland, Oregon, August 20-22, 1990. In: Technical Papers, Part 1 (A90-45845), American Institute of Aeronautics and Astronautics, 1990, pp. 234-244, 12 refs.

A90-45866#

Boundary-layer transition detection studies were carried out in the 0.3 Meter Transonic Cryogenic Tunnel on a supercritical airfoil, using an infrared imaging system. The purpose of the experiments was to determine the extent of the temperature range in which commercially available IR systems can detect transition in cryogenic environment. The experiment was designed to take advantage of a combination of factors including the wind-tunnel operation mode, the model construction materials and the IR system image processing options. During the initial phases of the study, the IR based findings were confirmed by measurements done with a micro-thin hot-film system. Ultimately, free and forced transition could be detected down to 170 K.

*Old Dominion University, Norfolk, VA 23508-0369 U.S.A.
**NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

635. *Yamaguchi, Y.; **Yoshida, S.; and *Kaba, H.: **Characteristics of a Cryogenic Wind Tunnel at National Defense Academy. (Part II) Tunnel Characteristics at Ambient and Cryogenic Temperatures. Technical Note.** In: Journal of the Japan Society for Aeronautical and Space Sciences, vol. 38, no. 441, October 1990, pp. 559-565, 9 refs., in Japanese, with abstract in English.

ISSN 0021-4663 A91-18071#

Note: For Part 1, see citation no. [626] in this bibliography.

From the previous operational experience for the high-speed cryogenic tunnel at National Defense Academy (NDA), its original manual control systems were partially modified, and a limited automatic control capability has been added. Though this modification was intended to improve the steady state operation, the control accuracy of both of the steady and transient operations was greatly improved, compared with that of the previous manual controls. The preliminary tunnel-calibration tests were intensively performed at both of ambient and cryogenic temperatures, and the results indicate that the NDA cryogenic tunnel satisfied the assigned specifications, and has sufficient potential to perform basic airfoil testings in a cryogenic temperature range.

*National Defense Academy, 10-20 Hashirimizu 1-Chome, Yokosuka-Shi, Kanagawa-Ken 239, Japan
**Japan Defense Agency, 7-45 Akasaka 9, Minato-ku, Tokyo 107, Japan

636. *Kilgore, R. A.: **Cryogenic Wind Tunnels.** Presented at the Symposium on Cryogenic Wind Tunnels held at ONERA/CERT, Toulouse, France, December 7, 1990, 10 pp., 32 refs.

We are often unable to get the data we need from wind tunnels because of things beyond our control. For example, until recently, low test Reynolds number has been a major problem, especially at transonic speeds. The development of cryogenic tunnels early in the 1970s offered the first practical solution to the problem of low Reynolds number. I first review some of the major problems with wind tunnels and comment on some possible solutions. I then explain why the cryogenic tunnel is one of the best ways to increase test Reynolds number and describe some of the first cryogenic tunnels. Finally, I present highlights of the present state of cryogenic tunnels with emphasis on liquid helium tunnels and activities in Japan and the U.S.S.R.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

637. *Mineck, R. E.; and *Hill, A. S.: **Calibration of the 13- by 13-Inch Adaptive Wall Test Section for the Langley 0.3-Meter Transonic Cryogenic Tunnel.** NASA TP-3049, December 1990, 109 pp., 11 refs.

N91-13461#

A 13- by 13-in. adaptive solid-wall test section has been installed in the circuit of the Langley 0.3-Meter Transonic Cryogenic Tunnel. This new test section is configured for two-dimensional airfoil testing. The top and bottom walls are flexible and movable, whereas the sidewalls are rigid and fixed. The wall adaptation strategy employed required the test section wall shapes associated with nearly uniform test section Mach number distributions. Calibration tests with the test section empty were conducted with the top and bottom walls linearly diverged to approach a nearly uniform Mach number distribution. Pressure distributions were measured in the contraction section, the test section, and the high-speed diffuser at Mach numbers from 0.20 to 0.95 and Reynolds numbers from 10×10^6 to 100×10^6 per foot.

*NASA Langley Research Center, Hampton, VA 23665-5225 U.S.A.

638. *Schnerr, G. H.; and *Dohrmann, U.: **Numerical Investigation of Nitrogen Condensation in 2-D Transonic Flows in Cryogenic Wind Tunnels.** Presented at the IUTAM Symposium, Göttingen, Germany, 1989. In: Adiabatic Waves in Liquid-Vapor Systems, by G. E. A. Meier and P. A. Thompson. Published by Springer-Verlag, Berlin-Heidelberg, 1990, pp. 171-180, 25 refs.

QC150.A35 1990

This paper discusses 2-D transonic flows of nitrogen, relevant to cryogenic wind tunnels, at the most critical initial values of high pressure and low temperature and with cooling rates (-dT/dt) of about 0.02 to 0.05 °C/μs which are representative of cryogenic transonic flows. For the first time, inviscid steady 2-D flows of nitrogen with nonequilibrium phase transition are studied numerically using the Euler equation coupled with the classical nucleation theory. The main droplet growth rates are calculated by a macroscopic law and the surface averaged droplet radius. Real-gas effects are not yet included. The theoretical values of adiabatic supercooling become nearly constant (15 to 16 K) and without exception, the onset Mach numbers are below 1.3. Due to the lower rates of heat addition in nitrogen flows near the Wilson point, only smooth compressions are observed for the lowest condensation onset Mach numbers. In detail, the 2-D propagation along subsonic heating fronts and the effects of different cooling rates are demonstrated in appropriate nozzle flows. Heat addition by homogeneous condensation in the flow around an inclined NACA-0012 airfoil affects the form of the supersonic regions essentially. Pressure drag and lift coefficients decrease simultaneously by about 19% and 37%, respectively.

*Institut für Strömungslehre und Strömungsmaschinen Universität (TH) Karlsruhe, FRG

APPENDIX A

A1. *Corruccini, R. J.; and *Gniewek, J. J.: **Specific Heats and Enthalpies of Technical Solids at Low Temperatures–A Compilation From the Literature.** NBS Monograph, October 21, 1960, 20 pp., 170 refs.

N63-81125

Tables are given of the specific heat, c_p, and the enthalpy of 28 metals, 3 alloys, 8 other inorganic substances, and 8 organic substances in the temperature range 1 to 300 K.

*National Bureau of Standards, Boulder Laboratories, Boulder, CO 80302 U.S.A.

A2. *Jacobs, R. B.: **Liquid Requirements for the Cool-Down of Cryogenic Equipment.** Advances in Cryogenic Engineering, Vol. 8, 1963, pp. 529-535. Presented at the Cryogenic Engineering Conference, Los Angeles, Calif., August 1962.

TP490.A3, Vol. 8

It is frequently necessary to estimate the amounts of cryogenic liquid required to cool cryogenic equipment to its operating condition. The purpose of this paper is three-fold: (1) to derive relations for making these estimates, (2) to compute the cool-down requirements for the commonly used liquids (helium, hydrogen, nitrogen, and oxygen) with some commonly used materials (stainless steel, copper, and aluminum), and (3) to present the results of the computations in a readily usable graphical form.

*National Bureau of Standards, Boulder Laboratories, Boulder, CO 80302 U.S.A.

A3. Pankhurst, R. C.; and Holder, D. W.: **Wind Tunnel Technique.** Sir Isaac Pitman and Sons, Ltd., London, 1965.

TL 567 W5P3

This book is an attempt to satisfy the need which the authors felt to exist for a coherent account of modern wind-tunnel practice written in the form of a critical resume rather than as a textbook which starts from first principles. It is intended primarily for graduates entering the field of experimental aerodynamics since it is felt that, although having a good knowledge of the theory, they may in many cases have had little opportunity of becoming familiar with experimental practice. It is hoped that the work may also be of value as a reference book for the research worker and for the model-testing personnel of aircraft firms. The scope of the book is best judged from the contents and forward references to the remainder of the text given in Chapter 1. For this reprint (1965) we have been able to correct known misprints and other errors (particularly the omission of the chord/span ratio from equations (3)-(5) on p. 238) but we have not introduced fresh material. The only substantial alteration occurs in Chapter VIII, where the drag correction ascribed to wall-induced inclination of the lift vector has been deleted in cases of two-dimensional flow.

A4. Barron, R. F.: **Cryogenic Systems**, 2nd Edition. Oxford Univ. Press, 1985, 507 pp.

TP482.B3 1985

This book gives an introduction to the engineering aspects and challenges of cryogenics. Emphasis is placed on the design and analysis of systems used to produce, maintain, and utilize low temperatures. The text is an outgrowth of class notes and lecture material associated with a course in cryogenic systems taught at Ohio State University. It is slanted primarily toward senior mechanical engineering students, although the text is arranged so that it may be used by an engineer unfamiliar with cryogenic techniques when he is called upon to assist in the design of a system for low temperatures. The required background for the student includes a knowledge of the basic engineering sciences-thermodynamics, heat transfer, fluid flow, and mechanics of solids. Because a book must always have a finite number of pages, not all topics in cryogenics are covered, but it is hoped that a student will have a firm foundation in cryogenics after studying this text. The text is intended for a one-semester undergraduate course in cryogenic systems. Books for additional reading are suggested at the end of each chapter.

*Louisiana Tech Univ., Ruston, LA U.S.A.

A5. *Scurlock, R. G.: **Low Temperature Behavior of Solids: An Introduction.** Rougledge and Kegan Paul, Ltd, London. Dover Publications, Inc., New York, 1966.

QC278.S43 (1966)

This book provides an elementary introduction to the behavior of solids at temperatures ranging down from room temperature. It is directed at the level of the second- or third-year undergraduate student in science and engineering and provides a concise account of some of the more important properties of the solid state. A strict mathematical approach is avoided and discussion is limited to qualitative, order-of-magnitude explanations of low-temperature behavior.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

A6. *Wigley, D. A.: **Mechanical Properties of Materials at Low Temperature.** Plenum Press, New York-London, 1971, 377 pp.

A72-19909

The aim of this book has been to consider the mechanical properties of the wide range of materials now available in such a way as to start with the fundamental nature of these properties and to follow the discussion through to the point at which the reader is able to comprehend the significance of (or otherwise) the large amounts of data now available in design manuals and other compilations. In short, it is hoped that this volume will be used as a companion to these data compilations and as an aid to their interpretation. Most of the materials likely to be of use in cryogenic engineering have been included, but despite the superiority of nonmetals for certain applications, it is a reflection of the major importance of metals that about 70 percent of the book is devoted to their deformation and fracture characteristics.

*University of Southampton, Department of Aeronautics and Astronautics, Southampton SO9 5NH, Hampshire, England

A7. *Reed, W. E.: **Cryogenic Refrigeration, Vol. 2. A Bibliography With Abstracts.** Progress Report, 1973–October 1977, NTIS/PS-78/1261/3, December 1978, 236 pp.

N79-16144#

Cryogenic cooling of electronic equipment, infrared equipment, cryogenic storage vessels, magnetohydrodynamic generators, superconducting magnets, coils, rotating machinery, and transmission lines is reported. Marine refrigeration of liquefied natural gas, cryogenic heat pipes, cryogenic heat transfer, and space applications are studied. Methods investigated include adiabatic demagnetization, electrocaloric effect, Joule-Thompson effect, thermoelectric cooling, and Crayton, Claude, Gifford-McMahon, Sterling, and Vuilleumier cycles. This updated bibliography contains 299 abstracts, none of which are new entries to the previous edition.

*National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 U.S.A.

A8. *Reed, W. E.: **Cryogenic Refrigeration, Vol. 3. A Bibliography With Abstracts.** Progress Report, November 1977–November 1978, 84 pp.

N79-16145#

Cryogenic cooling of electronic equipment, infrared equipment, cryogenic storage vessels, magnetohydrodynamic generators, superconducting magnets, coils, rotating machinery, and transmission lines is reported. Marine refrigeration of liquified natural gas, cryogenic heat pipes, cryogenic heat transfer, and space applications are studied. Methods investigated include adiabatic demagnetization, electrocaloric effect, Joule-Thompson effect, thermoelectric cooling, and Crayton, Claude, Gifford-McMahon, Sterling, and Vuilleumier cycles. This updated bibliography contains 77 abstracts, all of which are new entries to the previous edition.

*National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 U.S.A.

A9. *Wigley, D. A.: **Materials for Low-Temperature Use.** Engineering Design Guide, no. 26, Design Council, Oxford Univ. Press, London, England, 1978, 37 pp.

N83-78254

This paper includes the effect of temperature on the strength, toughness, and basic failure mechanisms in metals. It also includes the influence of cracks, flaws-fracture toughness, and time-dependent failure. The effect of temperature on the mechanical properties of non-metals and the effect of temperature on the physical properties of metals and non-metals are also discussed.

*Applied Cryogenics and Materials Consultants, Inc., 15 Cantamar Court, Hampton, VA 23664 U.S.A. or
Cryogenic, Marine and Materials Consultants Ltd., 17 Bassett Wood Drive, Bassett, Southampton SO2 3PT, England

A10. *Webster, T. J.: **Latest Developments in Cryogenic Safety.** Presented at the 9th International Cryogenic Engineering Conference (ICEC9), Kobe, Japan, May 11-14, 1982. NASA CR-166087, March 1983, 15 pp.

A82-46474#
N83-36276#

Some general aspects of cryogenic safety are highlighted and attention is drawn to some of the more unusual hazardous situations. An awareness of the physical properties of the cryogenic fluids being dealt with is important in directing attention to hazardous situations which may arise. Because of this, the more important properties of the cryogenic fluids are given, such as molecular weight, boiling point, and freezing point. From these properties, hazardous situations can be deduced. There are hidden hazards, most of which have led to deaths. These hazards are asphyxiation (anoxia), frostbite and hypothermia, explosions, and combustion. The aim of this publication is to help bring about increased safety in the production and use of cryogenic products through a deeper appreciation of the scientific, technological, and administrative steps which must be made if accidents, some fatal, are to be avoided in the future.

*Applied Cryogenics and Materials Consultants, Inc., 15 Cantamar Court, Hampton, VA 23664 U.S.A. or
Cryogenic, Marine and Materials Consultants Ltd., 17 Bassett Wood Drive, Bassett, Southampton SO2 3PT, England

A11. British Cryogenics Council: **Cryogenics Safety Manual-A Guide to Good Practice, Second edition.** Mechanical Engineering Publications, Ltd., London, 1982, 115 pp.

TP482.B7, 1982

This manual is a revision of the original *Cryogenics Safety Manual* published in 1970. It is aimed at those who are engaged in the production, handling, and use of cryogenic fluids, whether on a large scale in industry or on a small scale in research. The manual consists of five parts, the first of which is concerned with general safety requirements relating to all the cryogenic fluids and explains the hazards to health and the general precautions necessary in handling. The remaining four parts deal with specific fluids in groups or individually. Thus, Part II is concerned with oxygen, nitrogen, and argon, while Part III deals with liquified natural gas, ethylene, and ethane. Part III also contains nine Hazard Data Sheets describing the particular hazards associated with methane, ethylene, ethane, Pt. 3 propylene, refrigerant 22, benzene, hydrogen sulphide, butane, and propane. Part IV is concerned with the particular problems of handling hydrogen and Part V deals with the inert gases, helium and neon. The revision has been undertaken by a working group of the British Cryogenics Council bearing in mind the need for improved safety training and the continuing development and improvement of safety techniques and equipment. Experience has shown that all cryogenic fluids can be handled safely, provided certain precautions are observed. It is the purpose of this revised *Cryogenic Safety Manual* to focus attention on the basic precautions which are necessary.

AUTHOR INDEX

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SUBJECT INDEX

NOTE: The following index, although in no way complete, might be useful by giving an indication of where some material on definite subject areas may be found. Generally, surveys and summaries are not indexed in depth.

Entry

Report Documentation Page

NASA
National Aeronautics and Space Administration

1. Report No. NASA TM-4273	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle: Cryogenic Wind Tunnels — *A Comprehensive, Annotated Bibliography*		5. Report Date: April 1991
		6. Performing Organization Code
7. Author(s): Marie H. Tuttle, Robert A. Kilgore, and Deborah L. Moore		8. Performing Organization Report No. L-16919
9. Performing Organization Name and Address: NASA Langley Research Center, Hampton, VA 23665-5225		10. Work Unit No. 505-59-85-01
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, DC 20546-0001		13. Type of Report and Period Covered: Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

Marie H. Tuttle and Deborah L. Moore: ViGYAN, Inc., Hampton, Virginia.
Robert A. Kilgore: Langley Research Center, Hampton, Virginia.

Supersedes NASA TM-80168 (Oct. 1979), NASA TM-84474 (Sept. 1982), NASA TM-86346 (Apr. 1985), and NASA TM-4013 (Sept. 1987).

16. Abstract

This bibliography contains 635 entries. It updates and supersedes all previous NASA bibliographies on cryogenic wind tunnels. This updated version cites 168 additional documents. The intent is to list publications that would be useful to persons interested in building or using a cryogenic wind tunnel.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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